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ON VEGETATION MAPPING IN ALASKA USING LANDSAT IMAGERY

with primary concerns for method and purpose in  
satellite image-based vegetation and land-use mapping  
and the  
visual interpretation of imagery in photographic format

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USING LANDSAT IMAGERY WITH PRIMARY CONCERNS  
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15 Supplementary Notes Submitted to NASA in January 1977 as the final report on research contract NAS5-21833, Task 3, titled IDENTIFICATION, DEFINITION AND MAPPING OF TERRESTRIAL ECOSYSTEMS IN INTERIOR ALASKA			
16 Abstract Six vegetation and five land-use maps of diverse Alaskan areas, based on Landsat imagery, are presented. In conjunction, the central importance of vegetation in ecological affairs is emphasized, as is the need for vegetation knowledge and classification as prerequisites to mapping. (Method and purpose in Landsat image-based mapping, the utility of general-purpose vegetation maps, and problems of map comparison are elaborated.) Vegetation map verification is examined and developed. (Thus the role of Landsat imagery in vegetation science is explicated to some extent. The use of good imagery in photographic format is of leading concern.) The grouping of a wealth of visually obvious spectral signatures in a few easily managed classes is treated, as is the correlation of these classes with vegetations and other landscape features. Whereas the possible combinations of a few spectral classes on two images in conjunction with several physiographic positions exceeds the number of broad vegetation types in a map-area, the need to sort out great spectral detail by automatic processing of data is doubted. However, for large map-areas an initial machine-produced display, still to be interpreted by the vegetation scientist and put into proper map format, would be an expedient.			
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## Part I. INTRODUCTION

This report treats comprehensively research and related activities performed as Task 3 under terms of contract NAS5-21833 with the United States National Aeronautics and Space Administration (NASA). It also deals with work performed under terms of contract E00C14201079 with the United States Bureau of Indian Affairs (BIA). The latter was awarded through a cooperative arrangement with NASA and permitted extending the work in progress for Task 3 of the NASA contract. The writer of this report was the principal investigator for Task 3 of the NASA contract and for the BIA contract.

The original proposal to NASA (Anderson and Van Cleve 1971) emphasized ecosystems, including their identification, definition and mapping using Landsat (then called ERTS) data and imagery. As the research proceeded, emphasis shifted to vegetation because of the principal investigator's increasing awareness of the central and primary role of vegetation in the structure and function of ecosystems. Discussions and references in several places in this report attempt to justify this shift in emphasis. Special reference is made to a separate paper developed during the period of, and influenced by, the research reported here (Anderson 1976).

With the emphasis on vegetation, the focus has been on vegetation mapping. Vegetation mapping is a culmination of descriptive vegetation research and is basic in the study of ecosystems and in various investigations of a more theoretical sort. A vegetation map may be interpreted as an ecosystem map, as is the map Major Ecosystems of Alaska (JFSLUPCA 1973). Moreover, vegetation maps are of high applied value in land-use planning and management. Therefore this report deals mostly with applications of Landsat imagery in vegetation mapping, treating approaches, methods and longer-range goals whose importances became more apparent during the contract period. In support of vede-

tation mapping as a primary objective, discussions of the nature and purpose of vegetation mapping in general are presented. In addition, the description and classification of vegetation, which are major fields of endeavor in their own right and which are essential and usually prerequisite in mapping, are treated, particularly in Part VII. This treatment seems appropriate to this report inasmuch as there is a widespread tendency in the satellite remote-sensor community to handle the description and classification of vegetation (and other natural and cultural landscape features) in an uninformed or careless manner.

This report was written from the standpoint of a vegetation scientist exploring possible and straightforward uses of Landsat imagery for dealing with vegetation and related land-use problems. It does not represent the work of a remote sensing specialist or computer technologist trying to say something about vegetation.

Most of the research reported here dealt with Landsat imagery in photographic format. It appeared early in the project that interesting and useful work could be done with such imagery, and it was decided that the possibilities with this relatively simple and available form of imagery should be developed. This was particularly appropriate, despite being unfashionable, in view of the fact that a companion project was emphasizing the mechanical approach to Landsat imagery analysis and interpretation (McKendrick et al 1974). In general, most efforts to use satellite remote-sensor data seem to have overlooked the potential in the visual study of good photographic imagery by vegetation scientists familiar with the vegetation and landscapes in the study area.

The work reported here is product-oriented, in response to the apparent desires of NASA officials, expressed while the contract was under negotiation (Belon 1971: 12 ff). Hence several vegetation and land-use maps are presented (Figures 1, 3, 5-8, 11; Maps 1-6). Most of these are presented at full scale or slightly reduced, for these maps are meant to be used. Unfortunately, only cheap reproductions could be made to include with this report because of lack of money. This lack also precluded the presentation of imagery, with the exception of Figures 9 and 10 which are essential to the demonstration and training purposes of Part VII.

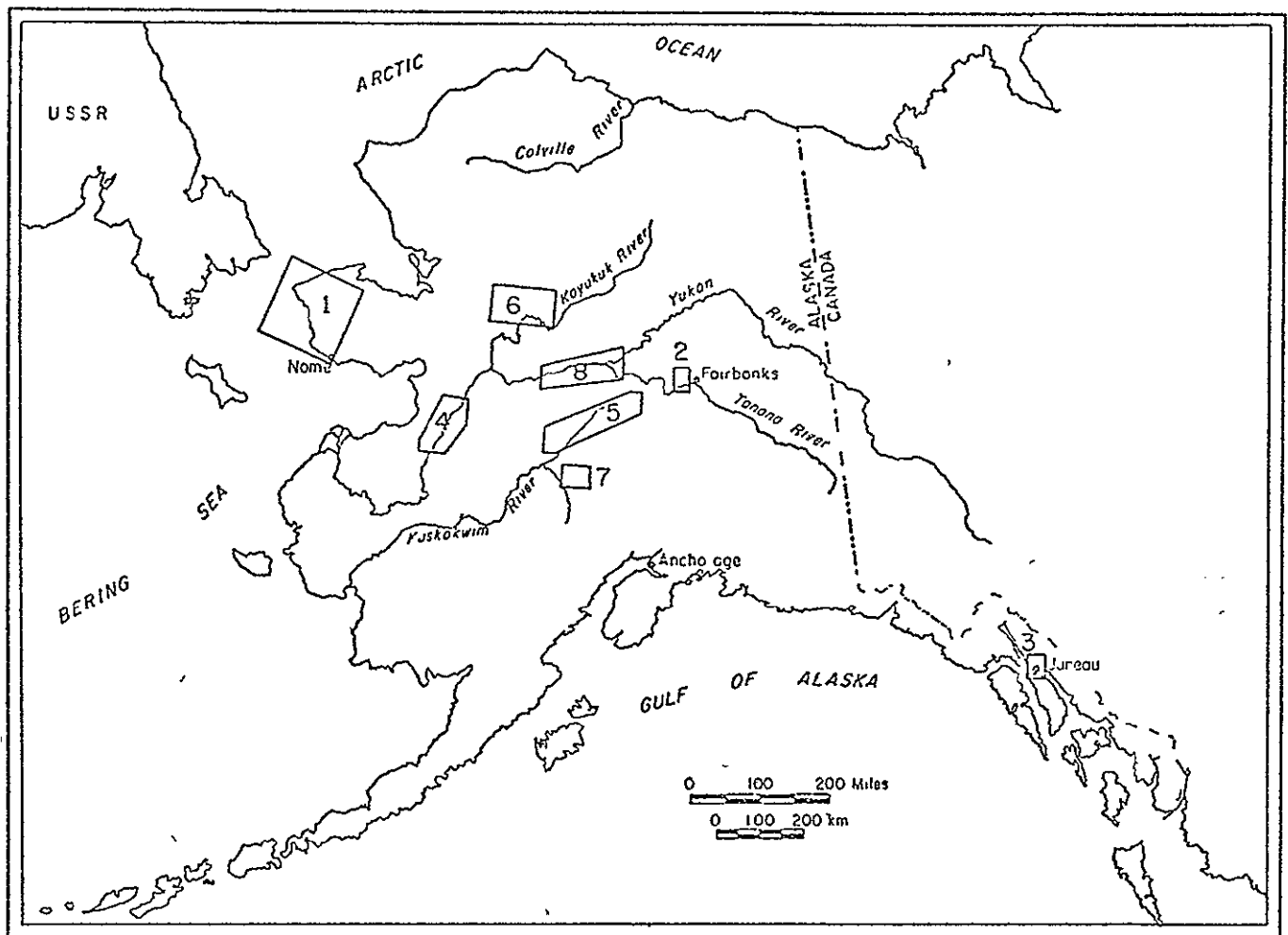


Figure 1. Outline map of Alaska showing approximate locations of areas treated in this report.

1. Western Seward Peninsula map-area. Part II; Figure 3
2. Tanana River-Bonanza Creek Experimental Forest-Murphy Dome map areas. Part III; Figure 5; Part IV; Figure 7; Part V; Figure 8; Part VII; Map 6
3. Juneau B-2 Quadrangle map-area. Part IV; Figure 6
4. Kaltag-Grayling map-area. Part VI; Map 1
5. North Fork Kuskokwim River map-area. Part VI; Map 2
6. Purcell Mountain map-area. Part VI; Map 3
7. South Fork Kuskokwim River map-area. Part VI; Map 4
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The following six parts constituting the body of this report are based mostly on papers written during the course of the research, some of which have been published (see below). The opportunity has been taken to condense, update and augment these papers and to revise them for standardization of format. Condensation has not been carried to the extent of eliminating all duplication, and the parts may therefore stand as semi-independent units. Frequent cross references between parts promote some integration.

References to the papers upon which the parts are based are as follows.

Part II. Anderson and Belon 1973. See also Anderson et al 1973; Anderson 1973b; Belon and Miller 1973; Maugh 1973.

Part III. Anderson 1974a. See also Anderson 1973a.

Part IV. Anderson 1974b.

Part V. Anderson 1974b.

Part VI. Anderson 1974c; Stringer et al 1974, 1975. See also Haynes 1975.

Part VII has not appeared before in publication or report form. Xerox copies of a manuscript representing an earlier version of Part VII have been distributed to a number of interested parties. A presentation at the XII International Botanical Congress in Leningrad (Anderson 1975) was based on materials in this part.

This report presents some original material. Section IV D and most of the text for Section IV C and Part V are original for this report.

Additional work was done with Landsat imagery by the writer during the report period but is not presented here because it was not done under terms of the NASA or BIA contracts. This work was covered by Anderson 1974d; Anderson et al 1974; Racine In press.

With the emphasis on vegetation and vegetation mapping, a number of botanical terms had, of course, to be used in writing this report. Common names of plants are used to the extent that these are well-established and widely recognized in botanical and lay circles.

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first appearance in a report part, a common name is accompanied by its Latin equivalent. The primary taxonomic authority recognized by the writer is Hultén (1968). A glossary of plant names and geobotanical terms used in this report is provided

Formal names of vegetation types included in a classification system used in the course of the research are capitalized, e.g. Shrub Thicket, Needleleaf Evergreen Woodland, Nonforested Wetland. Names of vegetation types or specific vegetations not formally classified, including several broad, catchall categories, are not capitalized, e.g. upland tundra vegetation, bog vegetation.

The term vegetation is used in two ways. (1) It is used in the general sense to refer to the total plant component of a place, e.g. "the vegetation of Alaska". This is the common use of the term. (2) It is used in a specific sense to refer to a unit of vegetation which may be undefined or defined at some classification level. Thus one may speak of "a vegetation" or "several vegetations". This usage is of considerable convenience and avoids the confusion often resulting from terms such as plant community, association, formation, phytocoenose, and various less common terms which have been defined and used in many different ways. In the interest of linguistic integrity, these terms should not be loosely applied, but withheld from the kind of use for which vegetation, in the loose but unit-oriented sense, is here accepted. These terms should be used only within well-defined contexts. The present use of the term vegetation is entirely consistent with common general and specific uses of climate(s) and soil(s). The logic of this is further emphasized when one considers that climates, soils and vegetations exist in nature as unitary complexes.

An attempt has been made to avoid confusing abstract and concrete considerations of vegetation. It is of fundamental concern in vegetation science that abstract considerations deal with vegetation classes or types (including associations), whereas concrete considerations pertain to vegetation units, i.e. stands, plant communities (vs. plant

community types), and phytocoenoses. Thus the casual reader may find the text, in a few places, slightly more awkward than would at first seem necessary.

It did not seem necessary to fatten this report with a special summary part at the end because of the summaries provided for Parts II, III and VII. The latter is the most comprehensive and is to be recommended first to the hurried reader. Overviews of various aspects of the research may also be obtained fairly readily from the discussion sections of Parts II, III and IV.

## Part II. A NEW VEGETATION MAP OF THE WESTERN SEWARD PENINSULA ALASKA, BASED ON AN EARLY LANDSAT IMAGE

### II A. Introduction

This part deals with the first attempt to identify and map vegetation as represented on a Landsat image. The image, the entirety of scene 1009-22095, the first good scene in color available to the project, is of the western Seward Peninsula, Alaska (Figures 1 and 2). The format was a photographic print at a scale of approximately 1:1,083,400 in simulated color infrared, reconstituted from MSS bands 4, 5 and 7. It was interpreted by direct visual examination and comparisons with published vegetation maps covering the western Seward Peninsula.

Mapping was done at the above scale, or approximately 1:1,000,000, a standard map scale and the smallest of the three standard scales of interest to this project. The others, 1:250,000 and 1:63,360, are dealt with successively in the following sections. Considering current needs in vegetation science, the limited availability of vegetation scientists and technicians, and the limitations of satellite imagery, it may be that the optimum use of Landsat imagery in vegetation mapping is at the 1:250,000 scale.

### II B. Methods

#### II B1. Approach

It is generally known that (a) vegetation covers all of the western Seward Peninsula except for water surfaces, sandy areas (mostly beaches and beach ridges), and rocky areas (high-elevation areas and lava flows) and (b) live vegetation in a normal physiological state appears on color-infrared photographs as some kind of red, gray-red or orange depending primarily on high-cover species composition, vegetation structure and plant density (Knippling 1969; Haugen et al 1972). Therefore, such colors on the image were assumed to represent vegetation, and color differences were assumed to represent differences in these vegetation attributes, hence in vegetation type. Six classes of more or less red colors were recognized and correlated with four broadly defined vege-

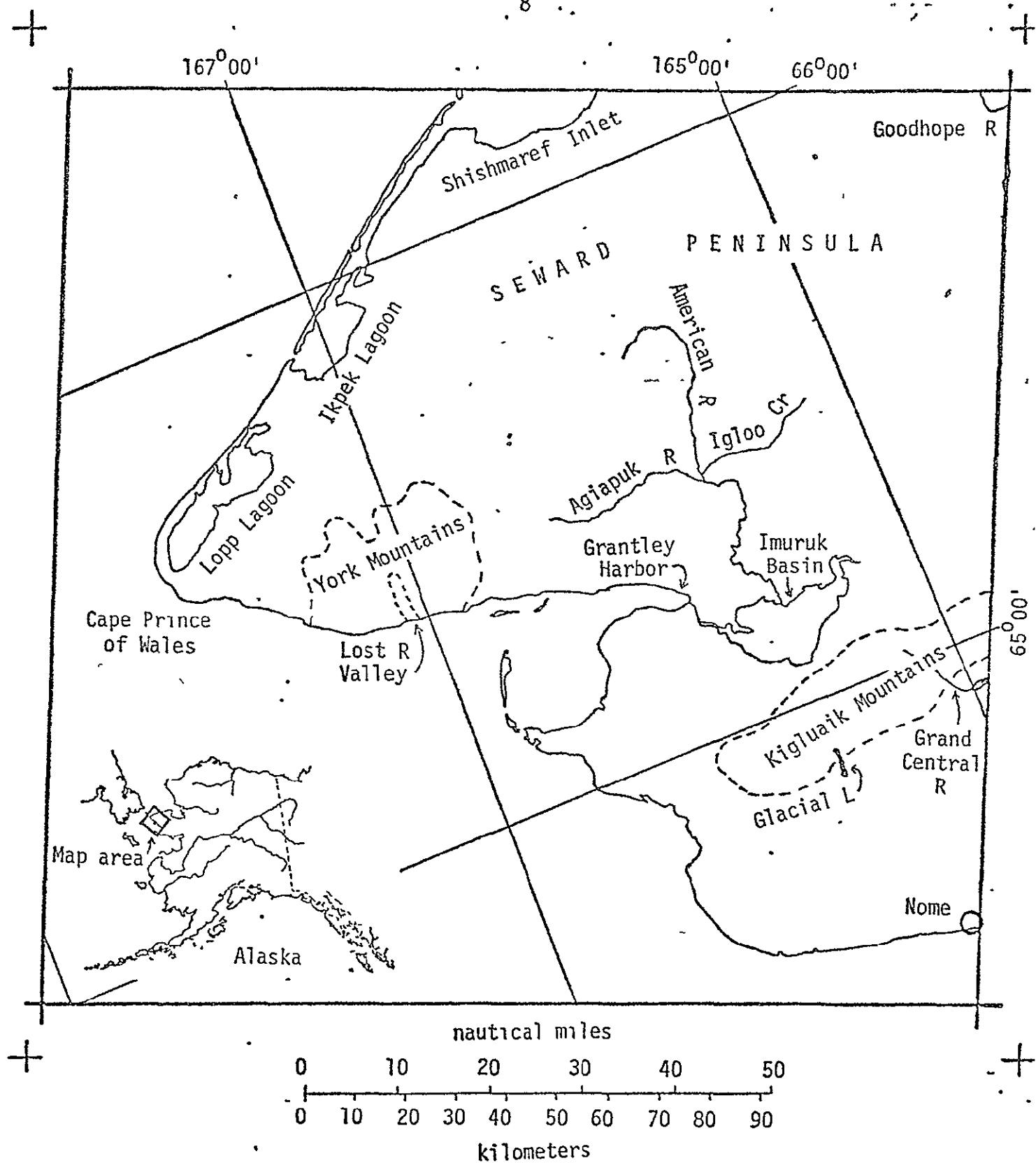


Figure 2. Map of the western Seward Peninsula, Alaska, showing features referred to in the discussion of the Landsat image-based vegetation map of the same area (Figure 3).

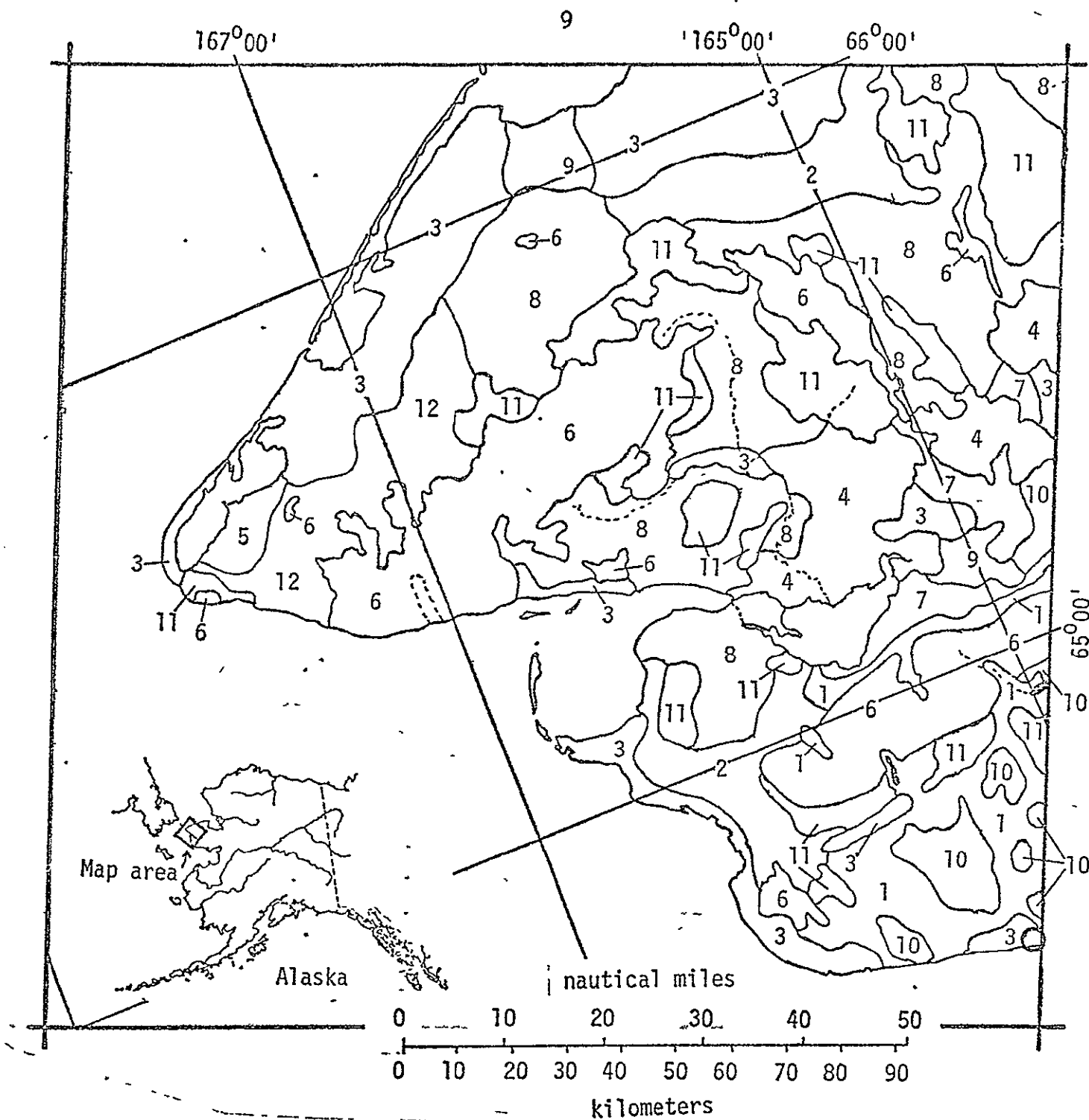


Figure 3. Vegetation map of the western Seward Peninsula, Alaska, based on Landsat scene 1009-22095; scale approximately 1:1,000,000. 1 = Broadleaf Shrub Thicket. 2 = upland tundra vegetation. 3 = lowland wet tundra vegetation. 4 = fire scars. 5 = possibly senescent vegetation. 6 = highland and mountain areas with sparse and no vegetation. 7 = possibly grass-dominated upland tundra vegetation. 8 = mosaic of 1 and 2. 9 = mosaic of 1 and 3. 10 = mosaic of 1 and 6. 11 = mosaic of 1, 2 and 6. 12 = 2 with some 5.

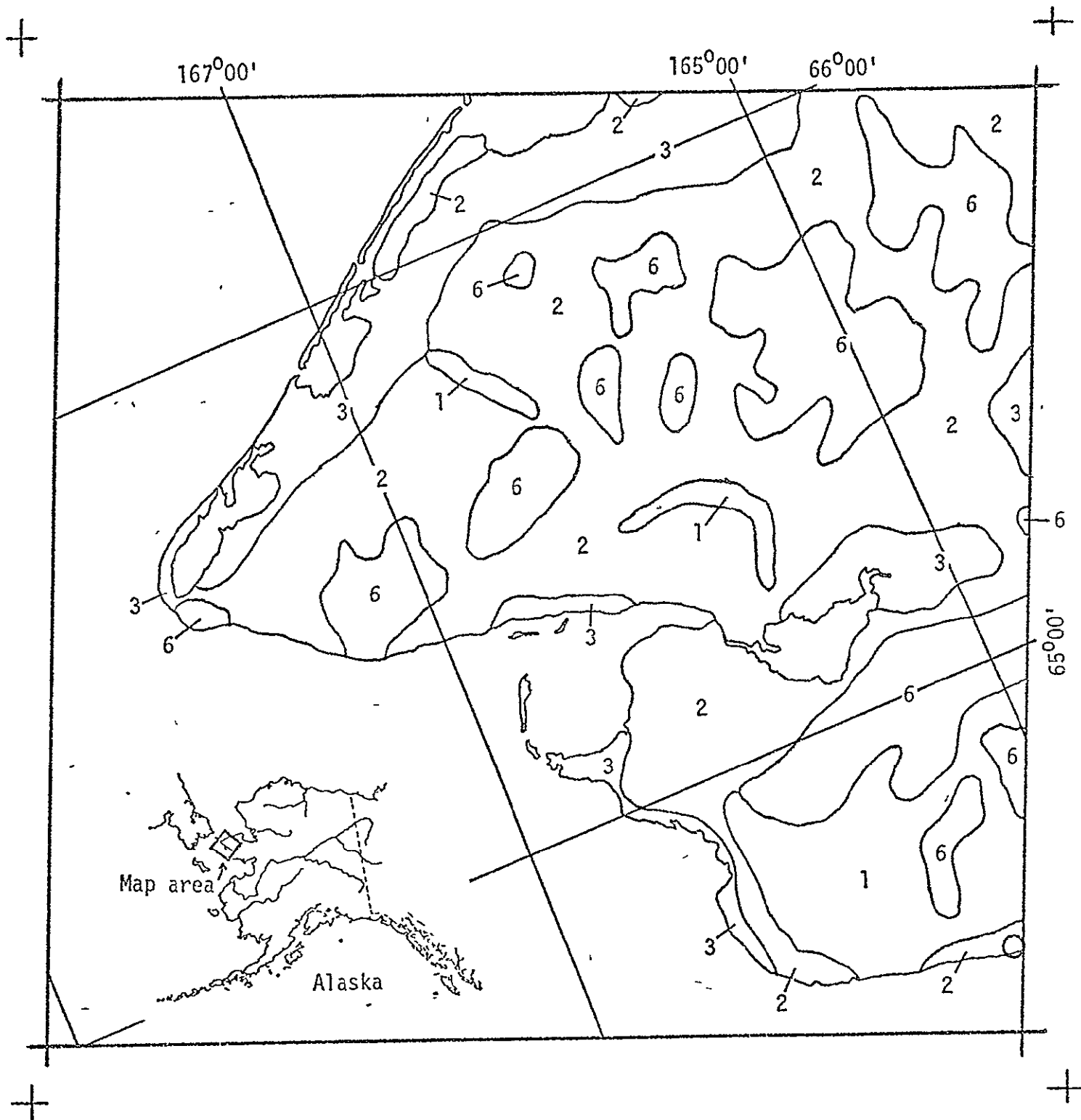


Figure 4. Vegetation map of the western Seward Peninsula, traced and enlarged from Spetzman's (1963) vegetation map of Alaska. The map unit classes identified by Spetzman and codes for their approximate equivalents as depicted in Figure 3 are as follows. 1 = High brush (1). 2 = Moist tundra (2). 3 = Wet tundra and coastal marsh (3). 6 = Barren and sparse dry tundra (6).

tation types and two kinds of vegetation-related phenomena. A seventh color, gray, represented mostly mountainous areas where vegetation is sparse or nonexistent.

Colors on the image constituted the fundamental information for delineating map units and, following correlations with available information, for identifying vegetations. Colors are considered as incorporating hue, value and chroma, but they were not evaluated other than visually, nor were they designated according to any standardized or quantitative scheme. A multitude of colors could be discerned on the image. Many of these were only subtly different and, in general, all the colors are thought of as members of a continuum. To deal with this wealth of spectral information, groups of similar colors, or color classes, had to be established and designated by common terms, as bright red, light gray-red, etc.

In addition to colors, shapes and patterns were recognizable on the image. Texture, however, was not discernable because of coarseness of resolution and therefore was unavailable for vegetation interpretations. Haugen et al (1972) were unable to discern texture for vegetation identifications on a similar image of the nearby Koyukuk-Kobuk River area to the east, whereon the resolution limit was judged to be approximately 80 m. In this regard, it is noted that no roads or other cultural features could be recognized on the present image. However, the western Seward Peninsula is sparsely inhabited, and the existing roads are short and narrow. Nome, the only town in the area (population around 2,500), in the lower right of the scene, was not visible.

Information for training and verification was limited to the published vegetation maps of Sigafoos (1958a), Spetzman (1963) (Figure 4), Kuchler (1967a) and Viereck and Little (1972). These maps depict four broadly defined vegetation types which are generally comparable in definition and distribution on each map. Four of the colors on the image were matched with these and identified accordingly. Identifications were supported by considerations of apparent physiographic positions and general information in the limited literature relating vegetation and

physiography. The three colors having no corresponding units on the published maps were tentatively identified as senescent vegetation, recently burned vegetation, and vegetation of a type not recognized by the earlier mappers.

Possibly available additional corroborative information, such as aerial photographs and unpublished field observations and data of other workers, was dismissed at the outset because it was desired to determine the extent to which an investigation could be meaningful using only the simulated color-infrared image and readily available information. This approach should be of practical value to some prospective users of Landsat imagery with limited resources at their disposal.

## II B 2. Image preparation (written by A. E. Belon)

Landsat scene 1009-22095 was reconstituted in simulated color infrared by photographing registered black and white positive transparencies successively through appropriate filters and using the Ektacolor process for producing an internegative color transparency and finished prints.

Owing to the very large density range and small format of the available 70 mm NASA products, 240 mm black and white positive transparencies with a smaller range of densities were made using the stepped density scale on the original negatives as a control for exposure and contrast. These transparencies, for MSS bands 4, 5 and 7, were placed in exact registration on a glass plate illuminated diffusely by a 3200° spotlight incident on a white lambertian screen placed at a 45° angle below the glass plate.

The registered positive transparencies were photographed successively as a multiple exposure on Ektacolor type L negative film using a Polaroid MP-3 copy camera equipped with Kodak Wratten filters No. 47 (blue) for the MSS band 4 transparency, No. 58 (green) for MSS 5, and No. 25 (red) for MSS 7. The exposure was determined by pointing a reflected light meter at each of the transparencies and compensating for the bellows extension factor, filter factor, and reciprocity failure



of the film material. The resulting color negative was processed according to Kodak recommended C-22 color negative processing chemistry procedures

Up to this point the data handling technique was standardized and no attempts were made to change the density or color balance of the negative by changing the relative exposures of the three MSS bands either in the production of the black and white transparencies or in the production of the composite color negative. In achieving a balanced Ektacolor print from such a composite color-infrared negative, the only reliable guide was the gray scale included on all Landsat products. However, this was not an ideal guide because prints which are not color-balanced may in fact enhance color difference areas which are related to vegetation or geologic patterns. Therefore Ektacolor prints with different color balances were produced. A subjective examination of these prints indicated that a balanced color print, slightly over-exposed, was best for vegetation identification and mapping.

## II C. Observations and interpretations

Units representing the seven color classes were outlined on a transparent plastic overlay of the image. The color units, the tentative vegetation map units, were then transferred to the base map over a light table. The 12 kinds of uniform and combination vegetation units were then labeled to produce the map in Figure 3.

The seven color classes were interpreted as follows.

### II C 1. Bright red. Broadleaf Shrub Thicket

A conspicuous occurrence of this color was a band across the lower northern slopes of the Kigluak Mountains, southeast of Imuruk Basin. In other places this color was associated with streams and upland lakes, such as the Grand Central River, Glacial Lake and several of the rivers flowing into Shishmaref Inlet and Ikpek Lagoon. This color was widespread as relatively small elongate spots in the upland areas throughout the scene. In many places these spots were connected in a dendritic pattern indicating an association with systems of smaller streams. In

the southeastern part of the scene the bright red color was prevalent.

Bright red was interpreted as representing the Broadleaf Shrub Thicket vegetation type. Its distribution approximately matched that of woody vegetation depicted on U S. Geological Survey topographic maps (Nome, Teller and Bendeleben sheets in the 1:250,000 series). There was general correspondence with the distribution of shrub-dominated vegetation as depicted on the four published vegetation maps cited above. Particular reference is made to the southeastern part of the image area where bright red was prevalent and where these maps showed a large area of shrub vegetation. Elsewhere, as along some of the larger northern rivers, the maps showed smaller areas of shrub vegetation corresponding with the general occurrence on the image of bright red along rivers.

In as large a land area as that of the present image, a shift in composition or structure of a broadly defined vegetation along a latitudinal gradient is likely. Some indication of such variation in the shrub thicket vegetation could be seen on the image. The bright red color had a violet cast in the south, as in the band across the northern slopes of the Kigluaik Mountains, whereas on the northern part of the image it was slightly orange. These two color phases could have been caused by differences in proportions of high-cover species. It is likely that in the warmer south, green alder (Alnus crispa ssp. crispa) and balsam poplar (Populus balsamifera ssp. balsamifera) are more important than in the cooler north, where willows (Salix spp ) and dwarf birch (Betula nana) may be the more prevalent species in shrub thicket vegetations. This conjecture is based in part on range maps by Viereck and Little (1975) and on the general climatic affinities of these species.

## II C 2. Light gray-red. Upland tundra vegetation

This was the most widespread color on the image. It occurred in large continuous patches or as a matrix for other colors, particularly bright red units, nearly everywhere except for the northwestern coastal zone and the mountains. On the southeastern part of the image it was secondary in areal importance only to bright red. The terrain rep-

represented by light gray-red appeared to be mostly uplands, including most flat and non-steeply sloping areas above the coastal plains and major valley bottoms and below the higher mountain slopes.

Light gray-red was interpreted as representing an upland tundra vegetation. Its range roughly matched that of the type designated moist tundra by Speczman (1963) (Figure 4) and Viereck and Little (1972) and cottonsedge tundra by Kuchler (1967a). It was generally comparable with the range of the vegetation termed herbaceous tundra by Sigafoos (1958a), except where he extended this type through the northwestern coastal zone. These designations refer to an upland, comparatively mesic tundra vegetation, in contrast to a lowland wet tundra vegetation. Correspondence with the published vegetation maps would be even closer were the range of the pink color, discussed below, combined with it.

Its wide distribution and variety in physiographic position indicate that upland tundra, more than Shrub Thicket and the others, is a diverse vegetation, consisting of several species in varying proportions. The species are predominantly herbs, including sedges (Carex spp.), cotton-grasses (Eriophorum spp.), grasses (Gramineae) and flowering dicots such as dryas (Dryas spp.); dwarf shrubs, including several ericads; and a number of cryptogam species. Unlike the bright red-Shrub Thicket case, no color variations which might have indicated major floristic or physiognomic variations within upland tundra were consistently apparent. Some color differences were detected, but the units were relatively small and local, they intergraded extensively, and it was difficult to identify similar colors from one place to another across the scene.

It is likely that patterned ground phenomena are common in the area of upland tundra vegetation. Hopkins and Sigafoos (1951) noted their prevalence in the Imuruk Lake area about 40 km east of the present image area. Some patterned ground phenomena, such as frost scars, peat rings and stone stripes, feature mineral soil and bare or dark lichen-covered rock exposed at the surface. The gray component of the light gray-red color may derive, at least in part, from these. Hummock and tussock development could be important in some places, as water in inter-tussock hollows could also contribute to the grayness on the image.

### II C 3 Medium gray-red. Lowland wet tundra vegetation

This color appeared as a wide band along the entire northwestern coast except for the area immediately east of Cape Prince of Wales (Figure 2), which was light orange-red. It occurred as a narrower band along parts of the southwestern coast, and it was tentatively identified in the area adjacent to the north side of Imuruk Basin. In the latter area the distinction from dark gray-red (see below) was rather subtle.

It was evident from its proximity to the sea and the abundance of lakes and ponds that the terrain represented by medium gray-red is low-lying and poorly drained. A preponderance of surface water and saturated soil was believed responsible for the gray color component. Plants probably stand in shallow water in most places.

The distribution of medium gray-red on the image approximately matched that of the wet tundra and coastal marsh of Spetzman (1963) (Figure 4), the watersedge tundra of Kuchler (1967a) and the wet tundra of Viereck and Little (1972). It was concluded that this color fairly accurately represented this variously designated type, which for present purposes is termed lowland wet tundra vegetation. According to information accompanying the published maps, this type consists predominantly of sedges and several grass species. The apparently more uniform topography and drainage indicates that large-scale vegetation variation in this type is minor in contrast to the highly variable upland tundra. Such variation as certainly occurs in lowland wet tundra vegetation is much too small of scale to appear on a Landsat image or to depict on a 1:1,000,000-scale map. Narrow strips of bright red color occur within wet tundra areas, presumably representing low-shrub vegetation along streams where ground water is more mobile and the permafrost table lower (Sigafos 1958b. Plate 13).

### II C 4. Dark gray-red. Fire scars

This color appeared as three large patches north and northeast of Imuruk Basin. It appeared to intergrade with medium gray-red north of

Imuruk Basin. In most places, however, the borders of these patches were abrupt and irregular, having no apparent topographic relationship. In other places streams formed parts of their boundaries, as where the northwestern edge of the western patch was formed by Igloo Creek.

The dark gray-red patches were interpreted as representing fire scars. The peculiar nature of their borders indicated this, and dark areas on color-infrared photographic imagery of other areas have been shown to indicate burned vegetation (e.g. Haugen et al 1972). It is generally known that tundra fires occurred on the Seward Peninsula within the past several decades. This was confirmed by records of the Bureau of Land Management which indicated, with one exception, a correspondence between areas burned in 1971 and the areas of dark gray-red on the image.

The exception pertains to the southern part of the western patch, adjacent to Imuruk Basin on the north. The Bureau of Land Management has not recorded a burn in this area. Therefore the dark gray-red color here may represent lowland wet tundra vegetation, even though the color was different from other areas identified as wet tundra vegetation. It is also noted that the western extension of this area, including a dark gray-red tongue reaching Grantley Harbor, seemed to lie on upland terrain and to have the apparently random boundaries of a burned area.

## II C 5. Light orange-red. Possibly senescent vegetation

The main area of this color was around Lopp Lagoon in the vicinity of Cape Prince of Wales. Southeast of here, in the vicinity of the York Mountains, it formed a matrix within which were scattered small patches of bright red and light gray-red colors. An orangeness appeared in the coastal wet tundra in the vicinity of Ikpek Lagoon, and a slight orangeness appeared in the upper Lost River Valley and throughout much of the area between Grantley Harbor and the western Kigluak Mountains.

The main area of light orange-red, and the other areas of basically different colors but with an orange cast, corresponded with no units on the published maps. Therefore this color may not be interpretable in

terms of a previously recognized vegetation type. A low amount of redness could be due to sparse plant cover, in which case the color observed could represent a ground surface of a predominantly mineral nature. The possibility that the surface here, in this coastal environment, is mostly sandy was considered. A sandy surface prevails at places in, for example, the Prudhoe Bay area. However, on the surficial geology map of Alaska (Karlstrom et al 1964), there is no indication of landscapes featuring sandy surfaces on the western Seward Peninsula. Furthermore, Haugen et al (1973) wrote that sand dunes appeared a light blue on the Koyukuk-Kobuk River area image. Finally, were the vegetation in the area under consideration truly distinct, it is likely that it would be depicted on the published vegetation maps. The area is sufficiently large to have been mapped even at the small scales of these maps.

It is suggested that the light orange-red color represented senescence in vegetations already identified, representing lowland wet tundra near the sea and upland tundra elsewhere. The image under consideration was obtained on August 1. It is possible that killing frost had occurred in this area just prior to this date, thus initiating the breakdown of chlorophyll in plant tissues. The growing season for the Seward Peninsula in general normally extends to a later date (Hopkins and Sigafos 1951: 55). However, summer temperatures may be, on average, a bit lower and the growing season a little shorter in the subarctic maritime environment of Cape Prince of Wales than in coastal areas farther south and interior areas. No orangeness appeared on the August 1 image in the latter areas. That the loss of chlorophyll from plant tissues may result in a decrease of red on color-infrared imagery was indicated by October photographs from the Forestry Remote Sensing Laboratory, etc. (1972) upon which alfalfa and cotton fields appeared orange-brown.

## II C 6. Highland and mountain areas with sparse and no vegetation

This color, in several shades, was that of mountains and terrain generally above the elevation limit of continuous vegetation. The

distribution of this color matched that of Sigafos' (1958a) map unit: rock desert, sand plains and bare rock. It compared with the barren and sparse dry tundra of Spetzman (1963) (Figure 4), the dryas meadows and barren of Kuchler (1967a) and the alpine tundra of Viereck and Little (1972). In the present work the sparse vegetation in the areas represented by gray was not referred to a type. Instead, highland and mountain areas with sparse and no vegetation were designated for mapping purposes (map unit 6). Patches of more nearly continuous plant cover lying within the highland and mountain areas may belong to the upland tundra vegetation type, although further considerations might lead to allocating these patches to a separate maritime-arctic alpine tundra vegetation type.

Vegetation in the highland and mountain areas is sparse, with the result that faint or no red color appeared. Gray represented surfaces of bedrock and rock broken up by weathering. In the mountains north and northwest of Imuruk Basin, limestone predominates (Dutro and Payne 1957), and the color here was light gray. Darker gray colors appeared in the Kigluaik Mountains where there are other kinds of rock at the surface. In a few small areas, non-red colors other than gray were seen, indicating granitic intrusions. These also are mountain areas with sparse plant cover. Geological interpretations of the present image were made by a different Landsat-1 investigator (L. Shapiro) and were presented separately by Anderson et al (1973) and summarized by Maugh (1973).

## II C 7. Pink. Possibly grass-dominated upland tundra vegetation

This color class, including light to medium reds, possibly smoother in texture than the other colors, was represented by a band contiguous on the north with the previously discussed band of bright red across the lower northern slopes of the Kigluaik Mountains. It was also recognized in the main valleys and on the south flank of this range. A relatively large pink area occurred adjacent to the many-ponded lowlands around Imuruk Basin on the northeast. Pink areas occurred elsewhere, e.g. a

large area in the mountains east of the upper American River, but here they appeared to be the result of bright red colors showing through thin clouds.

It is cautiously hypothesized that pink represented a tundra vegetation with a high proportion of grasses (map unit 7). As indicated above, this color appeared to occur as a relatively minor feature within the range of herbaceous-dwarfshrub upland mesic tundra vegetation as depicted on the published vegetation maps. Therefore it may have represented a variant of upland tundra, possibly one wherein soil frost action and surface water are relatively scarce. The absence of grayness may have indicated the latter. Where soil is more stable and better drained, vegetation may contain a high proportion of grasses. Grass cover is known in other areas to appear a bright pink on color-infrared photographs (e.g. illustrations in Laboratory of Agricultural Remote Sensing, etc. 1970).

#### II D Discussion

The interpretations presented above are tentative in lieu of map verification (see section VII 9). Conventional aerial photography could provide information for verification of this map, given the map's small scale and breadth of vegetation classes. It is likely that some aerial photography is available for parts of the western Seward Peninsula. Ground observations could also be useful. A few key areas could be selected with the aid of the Landsat image. Such areas might include the Nome area, the northern flank of the Kigluaik Mountains east of Imuruk Basin, the area north of Imuruk Basin, the area just inland from Lopp Lagoon and the area around Ikpek Lagoon. Appropriate verification observations could be made by flying low over these areas in a light aircraft. A loop trip out of Nome of about two hours duration should suffice.

Notwithstanding the lack of ground control, this early exercise indicated that a significant amount of vegetation and other landscape information may be obtained from Landsat imagery by direct visual examination and interpretation of photographic prints. Many colors can



readily be discriminated on images of this kind, and the color variation can be handled by allocating individual color units to a few classes. These classes may, to some extent, be correlated with vegetation types. All that is needed is adequate lighting, normal color vision and a well-prepared print. A low-power magnifying glass is helpful. A stronger glass, such as a ten-power hand lens, is useful at times. A primary need is knowledge of the vegetation in representative parts of the map-area, a need whose extent is governed by map scale, vegetation class breadth and mapping purpose.

Of the seven color classes recognized on the western Seward Peninsula image, one, bright red, appeared with two fairly obvious shades, violet-red and orange-red (the latter being different from the light orange-red discussed above), which may have indicated differences in species composition. The other colors showed variation too, but it was not possible to establish color shade definitions because of widespread interblending and the inability of the examiner to identify with reasonable certainty the color of a small patch in one place as the same as, or slightly different from, a patch in a different place.

The Landsat image studies provided, through interpretation, more information about vegetation than the published vegetation maps, a fact which is significant in view of the large area covered. A great deal of information for the same area could, of course, be obtained from conventional aerial photography, but only at a much higher cost.

The distribution of vegetation units representing the four types depicted on the published maps is shown in greater spatial detail on the image and on the new map (Figure 3). For purposes of comparison, Figure 4 is provided as a direct copy of the respective part of Spetzman's 1963 map, enlarged to the same scale as the map in Figure 3 and re-labeled for a non-color format. The new map clearly provides a better impression of the actual areal importance and the geographic ranges of the types. Shrub thickets in particular may be seen on the <sup>new</sup> map to be quite widespread, mostly as numerous small stands in upland drainageways throughout the map-area. These stands are too small to draw individually

on any but large-scale vegetation maps, i.e. larger than 1:100,000. Nevertheless they appeared collectively to occupy a significant area. On the present map (Figure 3) they are included in mosaic units 8 through 11. More detail in the distribution of highland and mountain areas may also be seen on the image. Whereas on the published maps these are simply encircled, they appeared on the image rather intricately interpenetrated with valleys containing a denser vegetation, primarily upland, or alpine tundra.

In addition to the more accurate areal assessment of the four known, broadly defined vegetations, an additional vegetation, possibly dominated by grasses, was indicated by the visual examination of the Landsat image. Further information which seemed to be available at the present level of examination pertains to the fire history of the landscape. The distribution of recent fires in this large area could be determined readily because of the distinctive dark gray-red color of burned areas. It is noted, however, that the maximum time a burned area remains recognizable on such imagery is not known, the burn areas identified here being only one year old, according to BLM records. Secondary vegetation succession occurs after fires, ultimately to restore an appearance or color which may or may not be distinguishable on Landsat imagery from that of non-burned areas, depending on whether the same or different species grow back. In another area of Alaska a spruce forest burn which occurred fifty years ago was readily recognizable on a color-infrared Landsat image because willows and aspens replaced the spruce trees in the burn area. A related but indeterminable factor may be the original degree of vegetation destruction wrought by a fire, hence of loss of red color.

Where extensive vegetation destruction by fire is known to have occurred and the immediate post-fire color was dark gray-red or gray-black, the degree of recovery some time later might be estimated from the amount of redness. On the other hand, in the case of a recent or current fire the extent of vegetation destruction or fire intensity might be estimated by the same parameter. For example, it should be

possible to distinguish on a color image creeping ground fires (less distinctive) from crown fires (more distinctive) in areas of Alaska which are more heavily forested than the Seward Peninsula. Future periodic Landsat imagery seems to hold promise for monitoring the development and spread of vegetation fires, hence of contributing to management procedures. Haugen et al (1972) indicated the rate of increase in size of a current burn in the Koyukuk-Kobuk River area. Beyond this, such imagery should provide a coarse view of vegetation recovery.

Finally, and of considerable potential importance, the Landsat image seemed to provide phenological information. As discussed above, the light orange-red color may have represented seasonally senescent vegetation. If so, the spatial gradation in intensity of this color, as between the shore of Lopp Lagoon and the northwestern foothills of the York Mountains, indicated that the Landsat system has some sensitivity to degree of senescence. A seasonal sequence of images might therefore provide a chronological and spatial survey of the development and deterioration of green plant material. This could be useful as an indication of certain weather developments, such as accumulation of degree-days.

## II E. Summary

A simulated color-infrared Landsat image covering the western Seward Peninsula was used for identifying and mapping vegetation by direct visual examination. The 1:1,083,400-scale print used was prepared by a color additive process using positive transparencies from MSS bands 4, 5 and 7.

Seven color classes were recognized. Units representing four of these were matched in approximate fashion with units on published vegetation maps: bright red = Shrub Thicket; light gray-red = upland tundra vegetation; medium gray-red = lowland wet tundra vegetation; gray = highland and mountain areas with sparse and no vegetation. In the bright red color two phases, violet and orange, were recognized and

tentatively ascribed to differences in species composition across the latitudinal range of shrub thickets. The three colors having no map unit equivalents on the published maps were tentatively interpreted as follows pink = grass-dominated upland tundra, gray-red = recent burn areas; light orange-red = senescent lowland and upland tundra vegetation.

A vegetation map was drawn by tracing on an overlay of the image. More information is depicted (Figure 3) than on published maps with regard to number of vegetation types and vegetation-related phenomena and the spatial distribution of units representing these (cf. Figure 4). Furthermore, the preparation of the new map from a Landsat image required little time relative to the use of air photos.

Conclusions based on this early work were (a) Landsat imagery is useful for studying diversity and distribution of broadly defined vegetations, (b) it is useful for drawing vegetation maps and has potential for revising vegetation maps, (c) sequential imagery should permit monitoring and damage evaluation of vegetation fires and the following of coarse phenologic changes, and (d) direct visual examination of Landsat imagery in place of more complicated and costly mechanical procedures can enable worthwhile interpretations.

PART III. A NEW VEGETATION MAP OF THE  
TANANA RIVER-MURPHY DOME AREA IN INTERIOR ALASKA  
BASED ON A LANDSAT IMAGE

### III A. Introduction

This part of the report tells how part of a single Landsat image in reconstituted color infrared was used for producing a 1:250,000-scale map depicting major vegetations in the Tanana River-Murphy Dome area near Fairbanks, Alaska (Figures 1 and 5). Whereas the image is not included here, discussions of spectral signatures, or colors, on it are presented as an indication of how a similar image might be used by others for vegetation interpretations and mapping. The image presented as Figure 10 was made from the same scene and covers the present map-area. However, it was made in a different laboratory by a somewhat different procedure, and its color balance is different. Hence direct reference to Figure 10 cannot be made in discussing the color interpretations treated in this part of the report.

The present map is preliminary pending (a) possible revision based on further air photo and ground control, (b) refinement of the vegetation classification and (c) critical review by vegetation and land-use scientists.

The map-area lies a few kilometers west of Fairbanks, is approximately centered on a point at 64°46' N lat X 148°31' W long, and is about 49 by 65 km, or 3,200 km<sup>2</sup> in size. It includes the Bonanza Creek Experimental Forest of the U.S. Forest Service, Murphy and Ester Domes, and segments of the Tanana River, the Fairbanks-Anchorage Highway and the Alaska Railroad. The topography is moderately diverse, with elevations from around 120 to 900m, and a considerable variety of vegetations occur here. These include lowland bogs and bog woodlands; upland bogs, bog woodlands, and broadleaf and needleleaf forests; a variety of shrub thickets; and, in a few small areas above about 750 m, subarctic alpine tundra vegetations. The interior Alaska part of the boreal forest biome seems to be represented here.

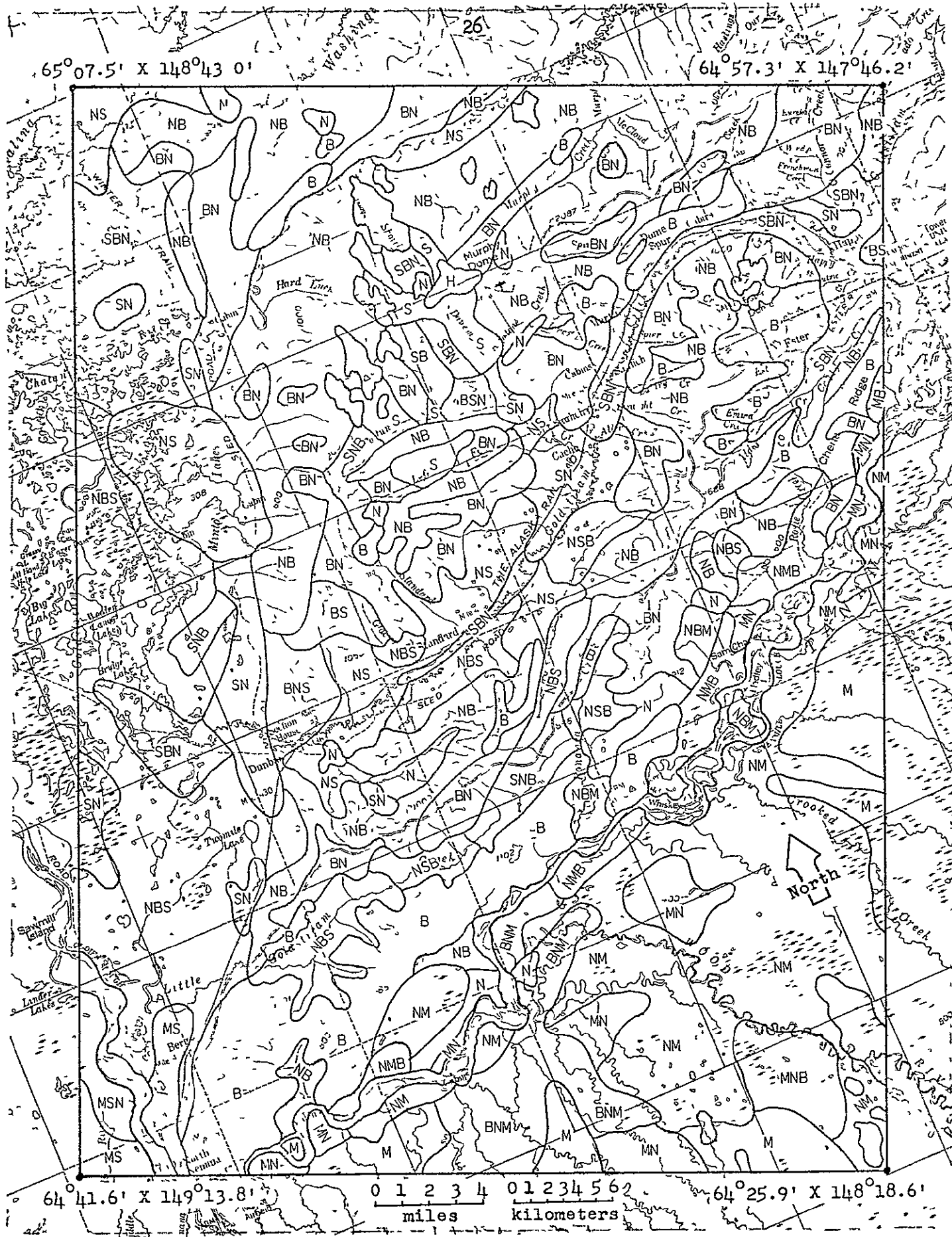


Figure 5. An early vegetation map of the Tanana River-Murphy Dome area. See following page.

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Figure 5 (preceding page). An early vegetation map of the Tanana River-Murphy Dome area based on part of Landsat scene 1033-21011 (cf. Figure 10). The map was drawn at 1:250,000 on parts of the Fairbanks and Livengood sheets in the U.S. Geological Survey series, but is presented here slightly reduced in scale for economy of reproduction.

B = Broadleaf Deciduous Forest, dominated by paper birch (Betula papyrifera) and aspen (Populus tremuloides).

M = bog vegetation, dominated by various dwarf shrubs, graminoids and bryophytes.

N = Needleleaf Evergreen Forest, dominated by white spruce (Picea glauca) or black spruce (P. mariana)

H = alpine tundra, dominated by dwarf shrubs, graminoids, bryophytes and various forbs.

S = Shrub Thicket and Shrubland, dominated by alders (Alnus spp.) and willows (Salix spp.).

In combination units, these vegetations are indicated in order of decreasing areal importance.

Unlabeled units are clouds.

The Bonanza Creek Experimental Forest Area of Part IV (Figure 7), the map-area treated in Part V (Figure 8), and the Tanana River-Murphy Dome Transect of Part VII (Figures 11 and 12; Map 6) lie within the present map-area.

### III B. Methods

The image used for mapping was a photographic print made from the southeastern part of Landsat scene 1033-21011 in the photographic laboratory of the Geophysical Institute, University of Alaska. The print was produced in simulated color infrared by the process described in Section II B and was enlarged to a scale as close to 1:250,000 as possible.

It is noteworthy that the cloud-free portion of scene 1033-21011 is only about 20 percent of the total scene area. Therefore this scene would probably not be selected by a prospective Landsat scene user from a listing of scene numbers and specifications in a catalog. Ironically, this scene was used more than any other in the research project.

The image was studied to discriminate color units to the extent that discrimination is possible with presumably normal color vision. Strong reflected light and transmitted light were tested, the former proving better. Five relatively uniform color classes were established: orange, gray, violet, dull violet and light violet. These colors occurred as units large enough feasibly to delineate and label at the 1:250,000 scale in a few places, but more frequently they occurred as mosaic components too small to delineate individually. Mosaics therefore were treated as map units. Blends of two and three colors were also recognized, and these too were treated as map units. A total of 26 kinds of mappable color units were recognized, including the five pure-color and 21 blend and mosaic units.

Color units were delineated by tracing them on a transparent plastic overlay of the image. The delineations were transferred over a light table to a base map made up of parts of the Fairbanks and Livengood sheets in the U.S. Geological Survey 1:250,000 series.

It was assumed that colors on the Landsat image resulted chiefly from the spectral reflectance of vegetation, since vegetation is known



to cover nearly the entire land surface in the map-area. This reflectance is that of the species or other taxa or life forms contributing most to the plant cover. These were considered dominant and were the basis of definition of vegetation types. It was further assumed that different colors resulted from different kinds of vegetation and that the array of colors on the image was indicative of the array of vegetations in the landscape. The colors and color combinations were correlated with vegetation types through comparisons with aerial photographs and considerations of available ecological information and field knowledge of the map-area.

### III C. Observations and interpretations

The five classes of more or less uniform colors and the vegetation types they represent are listed below. Vegetation types are defined at the level of formation or subformation as defined by UNESCO (1973). The UNESCO formation or subformation with which each type is believed to correspond closest is indicated by a number in a parenthesis.

Brief remarks regarding the dominant species are made, including some elementary information about their common physiographic affinities as an aid in map interpretation. Elevation, slope, aspect and, in a general way, drainage can be determined by careful inspection of the background topographic information on the map. In this manner plant communities dominated by one of two or more species with the same reflectance and appearance on the image may be tentatively located within the broader vegetations depicted. More thorough ecological information about the map-area and similar areas was presented by Lutz (1956) and Viereck (1973) and several of the authors they cited.

#### III C 1. Gray. Needleleaf Evergreen Forest (62) and Needleleaf Evergreen Woodland (86). Map symbol N

The dominant species are white spruce (Picea glauca) and black spruce (P. mariana). White spruce is more frequently the dominant in spruce stands adjacent to rivers, on upland flat sites and on slopes of

up to moderate steepness with a more or less southerly aspect. Black spruce is usually the dominant on lowland, flat and poorly drained sites and on slopes of a north or near-north aspect. Black spruce woodlands with a prominent understory of ericaceous shrubs and bryophytes are common on north slopes.

III C 2. Orange. Broadleaf Deciduous Forest (68) and Broadleaf Deciduous Woodland (91) Map symbol B

The dominant species are balsam poplar (Populus balsamifera), aspen (P. tremuloides) and paper birch (Betula papyrifera). As with the two evergreen species, large monospecific stands of these could not be distinguished on the image. However, balsam poplar occurs in significant stands only on floodplains near major streams. Aspen is important only on upland sites, particularly on the steeper southerly slopes. Paper birch as a stand dominant overlaps these species in physiographic range, although paper birch stands are less common on floodplains and the steepest south slopes than are balsam poplar and aspen stands, respectively. Paper birch is more frequently the deciduous forest dominant on upland flat sites and on slopes of most aspects up to moderate steepness. Aspen-dominated stands are of widespread secondary importance in all upland areas except on north slopes. Stands of mixed aspen and birch are common, but were indistinguishable from monospecific stands on the image. Aspen-birch stands are not readily distinguished from monospecific stands of either species according to physiographic position.

III C 3. Violet. Broadleaf Deciduous Shrub Thicket (109).

Map Symbol S

The principal species are alders, willows and shrub birch (Alnus spp., Salix spp. and Betula glandulosa). Monogeneric or monospecific stands of these were not distinguishable on the Landsat image. In the map-area thinleaf alder (Alnus incana ssp. tenuifolia) and green alder (A. crispa ssp. crispa) occur as stand dominants adjacent to major streams, especially on recent floodplains and on point bars. Several willow species also dominate on such sites. Large stands of willows occur on upland riparian sites and on various sites where former forest

vegetation was removed by fire. Certain species of willow are dominant components of the earlier stages of post-fire succession in many cases. In some cases upland areas appearing otherwise suitable for forest vegetation but currently bearing broadleaf deciduous shrub thickets are locations of fires which occurred within the past few decades. Such areas are commonly characterized by sharp, irregular and physiographically incongruous boundaries, revealed on the image by corresponding color boundaries. Shrub birch and dwarf birch (B. nana) are less common as stand dominants in this vegetation type, occurring as such only in the vicinity of treeline and in some lower-elevation flat areas.

III C 4. Light violet. Dwarfshrub, herb and moss tundra vegetations (191). Map symbol H

This color was of limited distribution on the image, occurring only at and in the vicinity of the highest summit, Murphy Dome. It could probably have been seen at one or two of the other highest places had these not been cloud-covered. These vegetations are characterized by several species of low-growing woody plants, bryophytes, graminoids and lichens. There are occasional sparsely vegetated and bare rocky places within the tundra zone.

III-C 5. Dull violet. Bog vegetations (144). Map symbol M

This broad vegetation category is represented extensively in the flat terrain south of the Tanana River and in the Minto Lakes area. The dominant plants are sphagnum mosses (Sphagnum spp.) and other mosses, sedges (Carex spp.), cottongrasses (Eriophorum spp.) and a number of dwarf/shrub species, the latter comprising ericads, dwarf birch and willows.

III D. Discussion

Only a minor portion of the map-area on the image was occupied by the five colors as uniform units large enough to map individually. In most cases colors could be mapped at the 1:250,000 scale only as blends

or mosaics. An additional 21 map unit classes were established to accomodate these mixtures which are believed to represent combinations of various-sized stands representing the vegetation types correlated above with the uniform colors.

Gray-orange, for example, is interpreted as representing a vegetation comprising either (a) a mosaic of relatively uniform and separate stands of broadleaf and needleleaf trees or (b) a mixture with individuals of each group more or less evenly distributed throughout. The map unit symbol is NB, and the order, with N first, indicates that the needleleaf component appeared more important areally on the basis of the apparent strength of the gray color relative to orange. Gray-orange color units in which orange seemed stronger were interpreted as indicating that broadleaf trees are more important in the vegetation. Here the map symbol is BN. Similarly, MNB designates a vegetation comprising a bog plant matrix with a black spruce component of low cover value and scattered stands of broadleaf trees.

Colors and the color balance on the Landsat image used in this work seem to be peculiar to it. They were different from the colors on a transparency of the same scene obtained from NASA's Landsat (ERTS) User Services whereon, for example, bright red appeared in place of orange. Colors are determined in part by the unique configuration of physical and chemical factors involved in the preparation of an image. Therefore photographic products produced at different times and, especially, by different people in different laboratories, are apt to be different, and a user will find it necessary to identify colors or color classes for himself and to establish the vegetation correlations with these.

This map and its preparation tend to confirm a conclusion from the work presented in Part II that Landsat imagery in photographic format can enable the inventory and mapping of broadly defined vegetations over large areas more efficiently than by the conventional use of aerial photographs. Although not a detailed map, the present one of the Tanana River-Murphy Dome area does provide more classificatory and spatial information than any published map of the area. It represents an application of a Landsat image to vegetation mapping at a commonly used,

intermediate scale (1:250,000), thus furthering the work of Part II where an image was used to map at the small scale of 1:1,000,000. Anderson et al (1974) demonstrated the use of a Landsat image for mapping vegetation in a western Seward Peninsula area at 1:250,000, and Racine (1975, In press) has more recently advanced the application here to 1:63,360.

### III E. Summary

A vegetation map of a 3,200 km<sup>2</sup> area just west of Fairbanks, Alaska is presented (Figure 5). This map was drawn through use of a Landsat image, part of scene no. 1033-21011 in simulated color-infrared photographic format, enlarged to a scale of 1:250,000. The map-area is phytocoenologically diverse and may fairly represent the vegetation diversity of interior Alaska. Vegetation information from the image was transferred to a 1:250,000-scale topographic map by way of a tracing on a transparent plastic overlay.

Five colors were recognized on the image and identified to vegetation types roughly equivalent to formations in the UNESCO (1973) classification: orange = Broadleaf Deciduous Forest; gray = Needleleaf Evergreen Forest; violet = Broadleaf Deciduous Shrub Thicket; dull violet = bog vegetation; light violet = subarctic alpine tundra vegetation. Frequently these colors occurred mixed as mosaics and blends, and 21 additional map unit classes were established to accommodate such mixtures.

The map is (a) an inventory of stands representing 26 broad kinds of vegetation, (b) a possible guide to work necessary for a spatially and classificatorially more refined map, and (c) an indication that vegetation maps of a usefully large scale may be produced for large areas through use of Landsat imagery more efficiently than by conventional methods.

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## PART IV. LAND-USE MAPS OF THE JUNEAU B-2 QUADRANGLE AND THE BONANZA CREEK EXPERIMENTAL FOREST AREAS, SCALE 1:63,360

### IV A. Introduction

This part deals with an attempt to use Landsat imagery in photographic format to make land-use maps at the large scale of 1:63,360. Two map-areas with quite different vegetations were selected, the area of the Juneau B-2 U.S. Geological Survey map quadrangle in southeastern Alaska and the Bonanza Creek Experimental Forest area in interior Alaska (Figure 1). The latter lies within the map-area of Part III and is dealt with further in Part VII. A part of this area is treated in even greater detail in Part V. Section VII C gives a basic description of a larger area containing the Bonanza Creek Experimental Forest area.

Inasmuch as these map-areas contain landscapes in which human disruption and alteration are still of minor areal extent, the land-use classes are mostly vegetation classes. The maps are called land-use maps because (a) the writer was temporarily impressed by the approach of referring landscape units, both natural and man-made, to land-use categories and (b) it was desired to try applying the new land-use classification system for use with remote sensor data under development by the U.S. Geological Survey (Anderson et al 1976). The reader is warned that an earlier version of this classification was used on the present two maps, a version whose Level I class codes are different from those of the final 1976 version. Codes from the final version were used on the five maps presented in Part VI.

### IV B. Methods

The images used for mapping represent parts of scenes 1019-19430 for the Juneau B-2 quadrangle area and 1033-21011 for the Bonanza Creek Experimental Forest area. Each scene was obtained from NASA in re-constituted color infrared as a nine-inch transparency. These photographic products were of exceptional quality and potential information value. Close examination with the unaided eye and low-power magnification led to the conclusion that more information interpretable in

terms of vegetation was visually available than could be dealt with even at the large scale of 1:63,360. This potential information was in the form of a large number of spectral signatures, or colors, in a complex and detailed spatial arrangement.

The map-areas were delineated on the scenes by masking their surroundings. The delineated portion of a scene was positioned in an enlarger and the projected image adjusted for scale to a topographic map on the enlarger easel. Several trial prints were developed, and the one showing the highest resolution, color diversity and contrast was selected for mapping.

The diversity and spatial complexity of colors were assumed to represent the arrangement of vegetations in the landscape. A few color classes were established to accommodate the many kinds of color units. This was necessary for convenience and because in many cases it was not possible visually to determine whether two or more units of similar colors in different locations were identical or slightly different in color. Units representing color classes were accepted as tentative map units. Groups of units representing different classes too small to map individually were accepted as tentative mosaic map units, and blends of colors representing different classes were accepted as tentative blend units.

The generalization involved in grouping a multitude of individual colors in a few classes was assumed to be compatible with the generalization involved in grouping a wide variety of plant communities or other kinds of plant assemblages in a few broad physiognomic classes. This assumption seems to be basic in vegetation mapping with remote-sensor imagery, and it was recognized in all the research reported here.

A map unit is tentative until its boundaries are finally adjusted and its vegetation identification established on the basis of information additional to the spectral and spatial information on the imagery. This additional information comprises (a) physiographic position, as determined with the topographic map, air photos and/or field observations, and correlations between physiographic positions and vegetation types

(Section VII E), and (b) correlations between color classes and vegetation types, as determined with air photos and/or field observations (Section VII G).

The term tentative vegetation map unit is used here instead of potential vegetation map unit to avoid confusion with the term potential natural vegetation as used and defined by Kuchler (1967a; 1967b 23). In the research reported here only the existing, actual vegetation was recognized.

Color class units were traced onto a transparent plastic overlay of the image, then transferred to a base map over a light table.

As in every mapping activity, there was a problem here of differential scale distortion between the Landsat image and the topographic base map. This problem and a technique for dealing with it are discussed in Section VII G.

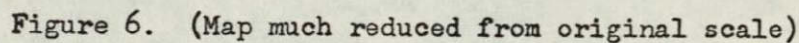
The process of correlating colors with different kinds of vegetation is discussed in Sections II B, III B and, more thoroughly, in VII G. In the Bonanza Creek Experimental Forest area, air photos from the 1972 NASA underflight series were the primary information source for this. The correlation of vegetations with colors on the Juneau area image was done mostly on the basis of the writer's field knowledge there and with a few pieces of literature, the most helpful being Neiland (1971).

#### IV C. The maps

##### IV C.1. The Juneau B-2 Quadrangle area map

This map is presented at a reduced scale as Figure 6. It was designated preliminary when it was made early in the course of the research and it must remain so because it has not been verified. However, for the breadth of land-use and vegetation classes depicted, it may be reasonably valid. It is an example of the use of a single large-scale Landsat image for vegetation mapping and the application of a popular classification system.







General definitions for unit classes represented on this map are provided in the published classification system (Anderson et al 1976). Area-specific descriptions follow below for the vegetation classes. Codes in parentheses are those used in the final, cited version of the USGS system and on the maps in Part VI. Names in parentheses are alternatives from the classification presented in Section VII D. Classes 4 1, 5 1 and 5 3 do not appear on the map despite their listing in the map key.

3 1 (4 1). Deciduous Forest Land. (Broadleaf Deciduous Forest)

Stands representing this class are of minor areal extent in the map-area, occurring almost exclusively on proglacial terrain in the Mendenhall River valley. Black cottonwood (Populus balsamifera ssp. trichocarpa) is the dominant species. It is usually mixed with large alders (Alnus spp.) and willows (Salix spp.).

Black cottonwood forests may be considered as representing an intermediate stage in succession to spruce-hemlock forests on glaciated terrain in southeastern Alaska.

3 2 (4 2). Evergreen Forest Land. (Needleleaf Evergreen Forest)

The principal species are Sitka Spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla). Tall and luxuriant forests dominated by these species are the characteristic feature in the landscape at elevations below the subalpine and alpine zones (classes 5 2 in part and 7 and 8 below). Tree heights are commonly around 150 feet. At higher elevations yellow cedar (Chamaecyparis nootkatensis) and mountain hemlock (Tsuga Mertensiana) are important forest constituents.

Sitka spruce-western hemlock forests may be considered as representing an advanced stage of succession in the map-area. Forests dominated by western hemlock alone, of common occurrence, are more nearly climactic. Both kinds are of considerable aesthetic and economic interest. It appears likely that on many sites and in the absence of disturbance or climatic change these forests eventually give way through paludification to bogs (Zach 1950; Neiland 1971). Upland bogs are of considerable importance in the landscape in the general southeastern Alaska region. However, the Landsat image indicated that in the map-area, bogs are of comparatively minor areal importance.

3 3 (4 3). Mixed Forest Land. (Broadleaf Deciduous-Needleleaf Evergreen Forest)

Like broadleaf deciduous forests, mixed forests also are of minor areal extent in the map-area. Mixed forests are characterized by combinations of black cottonwood, red alder (Alnus oregona) and Sitka spruce and may be considered as representing a late-intermediate stage in vegetation succession. They occur mostly on terrain in the lower Mendenhall Glacier valley freed from ice cover on the order of 100 to 200 years ago.

It is noted that vegetations representing later successional stages occupy most of the landscape in the cool maritime southeastern Alaska region. This is in contrast to the situation in the summer-warm and comparatively dry continental region of interior Alaska where many of the vegetations represent early and intermediate successional stages and where most of the research reported here was done. The overriding factors are the infrequency of vegetation fires in southeastern Alaska and their prevalence, as a principal ecological factor, in the Interior. In southeastern Alaska most vegetation disturbance is physiographic and, at present, localized. These disturbances are snow avalanches, landslides and valley glacierizations and associated glaciofluvial activity.

4 2 (6 2). Nonforested Wetland. (Bog and Marsh)

Nonforested wetlands in the map-area include (a) bogs, characterized by sphagnum mosses, ericads and some herbaceous species and a saturated peat substrate of considerable thickness, and (b) graminoid marshes, mostly in the lowlands adjacent to salt water, characterized by a dominance of sedges, a high water table and insignificant peat accumulation. Upland bogs develop under the influence of the wet and cool climate. They occur not only in topographic depressions, but also on flat areas and slopes where, as stated above, they may represent a late stage in vegetation succession.

5 2 (3 2). Shrub-brushland (Shrub and Brush) Rangeland. (Shrub Thicket)

Broadleaf deciduous shrub thickets dominated by Sitka alder (Alnus crispa ssp. sinuata) and varying proportions of willows are nearly continuous in the elevation zone between the forests and the various alpine tundra vegetations. Here they are a persisting member of a more or less classical sequence of intergrading vegetations along an elevation complex-gradient, from luxuriant forests at sea level to sparse forb and cryptogam vegetations in the upper alpine zone.

Elsewhere in the map-area, shrub thickets occupy disturbance sites. Alder-willow shrub thickets are characteristic of avalanche tracks, and many of these thickets are connected with the subalpine shrub thickets. Shrub thickets dominated by young black cottonwoods are common early vegetations on fresh proglacial terrain, as in the vicinity of the Mendenhall Glacier terminus.

7 (8). Tundra (Meadow, Shrub Thicket, Dwarfshrub Thicket, Fellfield, and Rock-surface Vegetation in the alpine tundra zone)

The various kinds of alpine tundra vegetation are widely represented in the map-area. It was not possible to distinguish them on the Landsat image, and they had therefore to be mapped together.

The Landsat image used to make the present map and an adjacent image made from the same scene were applied to the problem of determining changes in the surface areas of the terminal zones of advancing and receding glaciers. Three prominent glaciers, the Mendenhall, Taku and Norris, were measured by planimetry on the topographic maps of 1952 and 1962 and the 1972 Landsat images.

Table 1 gives the results of these measurements. The percentage changes by no means reflect size changes of the entire glaciers, but they do indicate terminus advance or recession during the measurement periods. The Taku advanced, whereas the nearby Mendenhall and Norris Glaciers, originating in the same icefield, receded. This situation, somewhat paradoxical on first glance, was treated by Miller (1964).

It would be difficult to measure on a Landsat image the surface area of an entire glacier in the Juneau Icefield complex because of widespread blending of the main glacier surface with late-lying snow and perennial snow patches at higher elevations and because of the

Table 1. Glacier terminal zone surface area changes. The upper limit of the measured zone is explained in the text. Changes are based on measurements made on older U.S. Geological Survey topographic maps (Juneau B-1 and B-2 quadrangles) and the 1972 Landsat scene, 1019-19430, enlarged to map scale, 1:63,360. Data are averages of several planimeter measurements selected from a larger number for negligible deviation.

GLACIER	AREA, km <sup>2</sup>		PERCENT CHANGE
	1962 map	1972 Landsat-	
Mendenhall	9.45	7.90	-16
	1952 map		
Taku	15.55	24.94	+60
Norris	7.11	6.68	-6

many interconnections with tributary and distributary glaciers. Only the terminal zone, clearly distinct in the late summer from adjacent terrain, can be measured, given a recognizable upglacier limit for this zone. In this exercise an upper limit was established by drawing a line across the glacier between two prominent stationary points near the glacier on each side that could be discerned on the maps and the images. These were peaks and small lakes. Hence the terminal zones measured are somewhat arbitrary, but the changes should be of some interest.

As recognized above, this kind of change may have little meaning relative to the regime of an entire glacier. Nevertheless, this exercise indicates a potential for the study of glacier terminus changes through use of Landsat imagery. The enlarged photographic image upon which planimetric measurements are easily made is a key feature of the technique. Such images in black and white format could readily be obtained for most glacierized places. With future Landsat imagery, glacier fluctuations could be inventoried periodically. In this context the arbitrary line across a glacier delimiting the terminal, measured zone could, as a permanent reference, be of some importance.

#### IV C 2. The Bonanza Creek Experimental Forest area map

This map is presented at a reduced scale as Figure 7. General descriptions of the map unit classes are in the published USGS system (Anderson et al 1976). Area-specific descriptions may be derived from Sections III C and, particularly, VI C. As with the preceding map, the status of this one also remains preliminary.

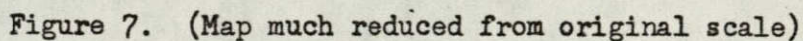
#### IV D. Discussion. On the subject of vegetation map comparison

The Bonanza Creek Experimental Forest area map and the maps of Figures 8 and 11 and Map 6 provide a considerable amount of common areal coverage. A comparative evaluation of these three maps seems therefore to be in order. This would not be an easy and straightforward matter. Attempts to design and test a method for comparing these maps, or other vegetation maps of a single area elsewhere, would have been outside the scope of the NASA-contracted research. However, the subject is relevant, and ideas on the comparison of vegetation maps were inspired by the work. Hence it would be of interest here to mention briefly seven chief problem areas which have become apparent. This somewhat theoretical discussion will refer, as a shorthand tactic, to map A and map B, the maps of Figure 7 and Figure 11 and Map 6, respectively, or two hypothetical maps of a single area.

(1) The sizes of the units on map A are on the average smaller and more appropriate to the scale of 1:63,360 than those of map B. The latter, i.e. Map 6, as will be seen in Part VII, is essentially an enlarged 1:250,000-scale map. The units of map A were estimated to average 69.5 percent the size of map B units, based on a line-intercept sampling method. The considerable but intentional difference in mean map unit size between the maps would hinder map comparison.

(2) The boundaries of the map A units are rather crooked compared with the smoother boundaries of the map B units. This difference, in addition to the average unit size difference, stems mostly from the use of a 1:63,360-scale image for drawing map A and 1:250,000-scale images







for map B. Generally speaking, whereas a high degree of spatial information may be apparent on an image, only a certain optimum amount can feasibly be portrayed at a given scale. The optimum amount of mappable spatial detail depends on the skill, time and facilities available for drafting and reproduction and, especially, on the necessity that the map be legible. It follows that there is a minimum practicable map unit size. Regarding the present maps, it is noted that minimum unit sizes are smaller on the original 1:250,000 version of map B (Figure 11) than on map A, meaning that more spatial detail relative to scale is shown here than on map A, a fact which is belied by the Map 6 enlarged version of map B.

(3) In consequence of the preceding factors and disregarding for the moment classification differences, it is to be expected that spatial compatibility between units on the two maps will in general be lacking. Therefore an estimation of how well the two maps compare could not be based on the extent of map unit spatial correspondence.

(4) The classifications used with these two maps were different, although not greatly so, and some of the assumptions by which vegetations were assigned to classes changed, from those used in applying the USGS system in developing map A to those used later when the modified Fosberg-Viereck classification (Section VII D) was applied in making map B.

It would be difficult to compare items identified according to certain criteria and with certain names in one classification system, with items identified according to different criteria and with different names in another.

A further problem arose in the research reported here in connection with adopting assumptions for allocating given vegetation phenomena to classes within and between the different classification systems. The most often encountered case was as follows.

A common kind of vegetation in interior Alaska, well represented in the present map-area, has among its leading characteristics (a) needle-leaf evergreen trees (black spruce) of small, frequently stunted growth

form in an open to scattered, but nonetheless conspicuous arrangement, (b) shrubs and, mostly, dwarf shrubs forming a closed or somewhat open secondary layer, and (c) a substrate which is wet, although not wet as in a marsh or wet meadow. Further, this vegetation is represented on flat sites as well as on slopes in the lowlands and the uplands.

Although their actual states differ among stands, these variables are of common importance for classification purposes at a gross physiognomic level. The USGS system, however, requires that one of them be emphasized. By (a) this vegetation would be Evergreen Forest Land, by (b) Shrub and Brush Rangeland (an unfortunate term), and by (c) it would be Forested Wetland. In developing map A, stands of this vegetation in the lowlands were classified in most cases as Wetland, Forested or Nonforested depending on estimations of tree density. Similar stands in the uplands were considered Evergreen Forest Land. Later, in making map B, a more nearly equal emphasis was laid on each variable, leading to classification of this vegetation in both lowland and upland areas as Needleleaf Evergreen Woodland. This class is briefly defined in Section VII D. The term woodland distinguishes this vegetation from forests in a way not possible at Level I or II of the USGS system. Woodlands and forests are major different physiognomic kinds of vegetation of equal rank that must be distinguished at the highest classification level. It also indicated the distinction from shrub thickets, but it is so defined as to imply the characteristic of a prominent secondary vegetation layer, which in this case is shrub or dwarf shrub thicket.

In order to compare map A and map B, the map unit identifications would have to be translated into one classification or the other, or a third serving as an arbitrary standard. It is doubtful whether equivalencies could be more than partial, mixed or overlapping.

(5) A most serious obstacle to vegetation map comparison stems from the fact, often overlooked by the casual map reader, that only the most prevalent vegetation or vegetations is or are identified for a map unit. These vegetations are only those which occupy significant portions of a map unit area. Usually, in mosaic and blend units, no more than

three vegetations are involved. Up to two are identified on map A (Figure 7) and up to three on map B (Map 6). The mechanics of labeling the smaller map units place some limitations on the number of vegetations which can be identified. However, the chief reason for the limited number of prevalent vegetations identified for a map unit is that the units are drawn whenever possible so as to encompass no more than three such vegetations. By convention, these vegetations are those which together occupy approximately 80 percent or more of the unit area.

In comparing maps, one might select sample points or small sample areas in the landscape and try to establish that they were similarly identified vegetation-wise on each map. However, with only the most prevalent vegetations identified, there is only a certain probability for a given map that an indicated vegetation actually occurs at any point. Therefore probability estimates for each map unit class would have to be available before a point-for-point comparison could be made. Such estimates would depend on a sampling procedure beyond the scope of the project covered by this report. Moreover, it is likely that even if class equivalencies between the two systems could be established, probability estimates for equivalent classes would be different between the two maps, further complicating the problem.

If it were assumed, as a working hypothesis, that a point-for-point comparison would be a valid approach, such a comparison would have to be done in the context of a unit-for-unit comparison between maps. This implies stratified sampling based on groups of sample points within unit areas spatially coincident between the two maps. But this would not be feasible because of the above-discussed lack of spatial coincidence between units on the two maps. There is, of course, extensive overlapping, but overlap areas tend to be too small and unfavorably distributed for representativeness to contain a number of sample points sufficient for statistical validity.

(6) It is suggested that there are three basic approaches to the comparison of vegetation maps as follows.

(a) The maps might simply be evaluated one against the other such that a statement regarding their similarities or differences could be made. Two maps might be nearly identical, both spatially and in terms

of classification, or they might be quite different. The differences might be expressed quantitatively by some sampling procedure. This approach would be the least meaningful because it would not necessarily involve any relationship of either map to the real situation in the landscape. Nevertheless, this is the kind of comparison some people seem to have in mind when they ask how one map compares with another.

(b) In the second approach, one map would be accepted as "correct" and the standard for comparison on the basis of knowledge that it represented reality to an acceptable known degree. Another map would be evaluated against it. The objective might be a quantitative estimate of how well the second map measured up to the first, or of how "wrong" it was.

(c) According to the third approach, no attempt would be made directly to compare one map against the other. Instead, each would be compared with reality, through actual field checking, use of air photos, or both. Thus separate estimates of the degree of correctness of the maps would be produced. The maps could then be compared indirectly insofar as one was known to represent reality to some degree, while the other was known to represent reality to some greater, equal or lesser degree. The degree-of-correctness estimates would have to be made by a standardized sampling and analytical procedure so that the maps would in fact be comparable.

This approach would be the most realistic and meaningful. It involves vegetation map verification, a subject of further complexity and unresolved problems which is treated at some length in Section VII I. As indicated above, a degree-of-correctness estimate is developed in Section VII I for the Tanana River-Murphy Dome transect map. If similar estimates for the Bonanza Creek Experimental Forest map (Figure 7) and the map of Part V (Figure 8) were made, a basis for a map comparison might finally be at hand. However, even then it would have to be acknowledged that each map represented reality only within the context of its own scale, classification and purpose. These factors add up to three different kinds of maps, the comparison of which would be somewhat analagous to trying to compare an apple, an orange and a banana.

(7) Finally it must be remarked that persons who've seen maps produced by the project reported here usually ask how a map compares with another from the project or with maps resulting from entirely different efforts (maps mostly of different scales, with different classifications, and for different purposes). However, there has been only reticence with regard to the specifics of approach and technique in vegetation map comparison.

PART V. A LARGE-SCALE MAP OF HIGHEST-COVER PLANTS  
IN THE BONANZA CREEK EXPERIMENTAL FOREST AREA

This map (Figure 8) represents another attempt to deal with an abundance of visually obvious spectral information interpretable in terms of vegetation, or plant cover. The image used was the same as was used to make the map of Figure 7.

In the present exercise the emphasis was two-fold: (1) It was desired to demonstrate more thoroughly the amount of spatial information on the image by delineating smaller map units than were shown on the map of Figure 7 and than could be shown on the map of Map 6 (see part VII) (2) It was desired to identify the map units as individuals and not as members of a few classes. It was thought that in this manner a botanical map portraying the real plant cover more concretely than a vegetation map per se could be produced. The vegetation maps treated in the other parts of this report use, like most vegetation maps, classifications based on the type concept of vegetation and therefore represent the real plant cover in a more abstract fashion than a botanical map on which units are identified individually. This is because on the latter kind of map no limit is imposed on the number of highest-cover plant assemblages which may be recognized. This approach may be more nearly compatible with the real diversity in the landscape. On the other hand, a botanical map of the present kind is more complex than a vegetation, or vegetation type, map. Hence it might not be feasible to produce or use such a map for large areas.

The map units were identified using air photos covering a part of the map-area and the mapper's limited knowledge of relationships between principal taxa and physiographic positions. These principal taxa are the species and species groups contributing most to plant cover, thus most to the spectral reflectance recorded on the image. All botanical terms are listed in the Glossary, and the use of information on physiographic position is discussed in Section VII E.

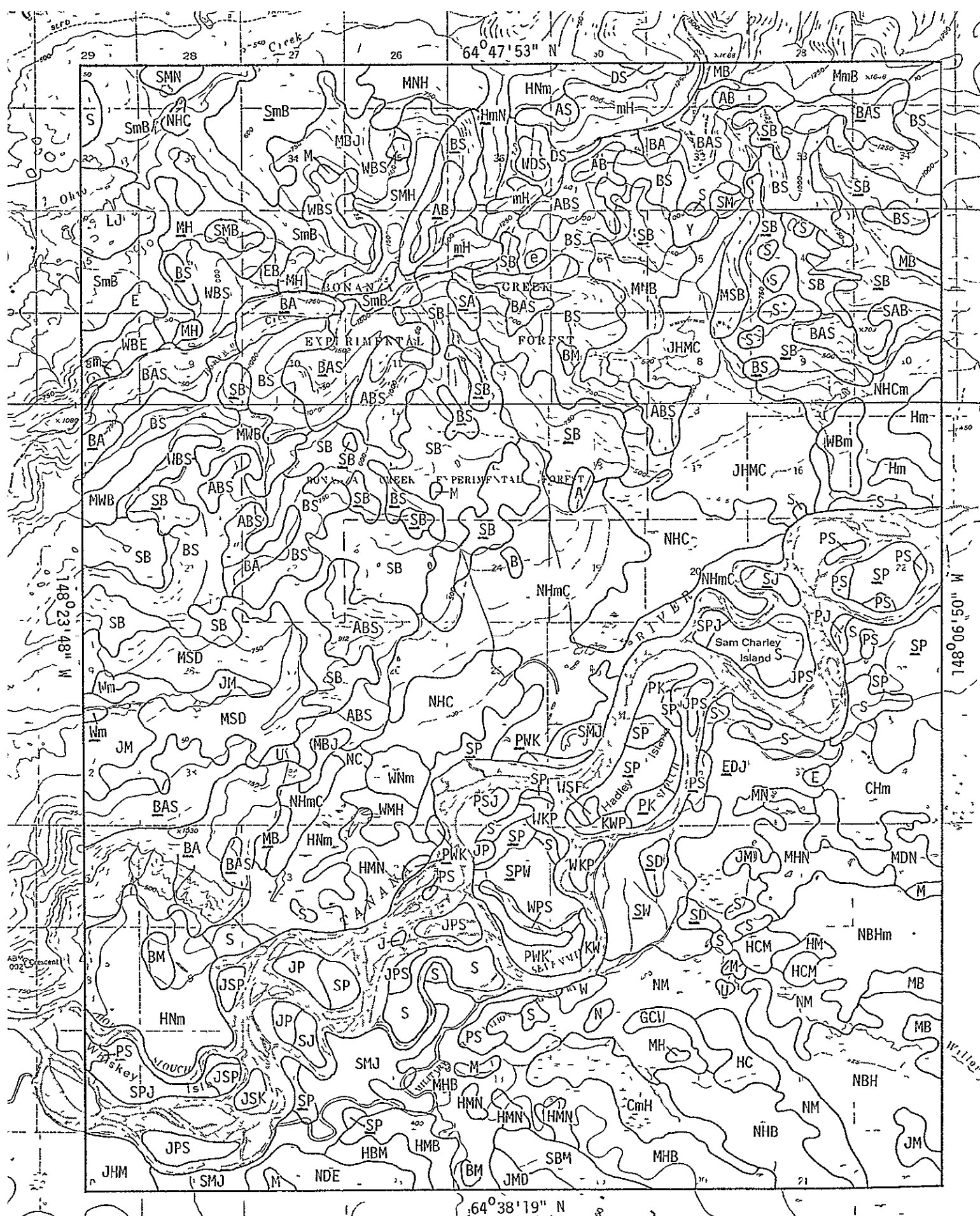


Figure 8 Map of highest-cover plants and plant assemblages in the Bonanza Creek Experimental Forest area in interior Alaska. See legend on following page. Reduced from original scale of 1:63,360

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Figure 8 (preceding page). Large-scale map of highest-cover plants and plant assemblages in the Bonanza Creek Experimental forest area in interior Alaska.

- A = Aspen (Populus tremuloides)
- B = Paper birch (Betula papyrifera)
- C = Sedges and cotton grasses (Carex spp. and Eriophorum spp.)
- D = Broadleaf deciduous trees, undifferentiated
- E = Needleleaf evergreen trees, undifferentiated
- F = Forbs
- G = Grasses (Gramineae)
- H = Heath plants, or ericads (Ericaceae)
- J = Broadleaf shrubs, undifferentiated
- K = Alder (Alnus crispa ssp. crispa and A. incana ssp. tenuifolia)
- L = Low-statured plants, undifferentiated
- M = Black spruce (Picea mariana)
- N = Shrub birch (Betula glandulosa) and dwarf birch (B. nana)
- P = Balsam poplar (Populus balsamifera ssp. balsamifera)
- R = Recently burned area
- S = White spruce (Picea glauca)
- U = Unclassified
- W = Willows (Salix spp.)
- X = Bare ground
- Y = man-disturbed area

In combination units, letters are arranged in order of decreasing areal importance of indicated plants. Lower-case letters indicate trees less than around 5 m in height. Underlined letters indicate plants of very high importance relative to the others in a combination-unit area.



Codes for the highest-cover plants were assigned as logically as possible to promote map comprehensibility. A = aspen, B = paper birch, S = white spruce, etc. Still, several arbitrary assignments had to be made (see key for Figure 8).

The map unit codes provide considerably more information than just plant identifications. (1) The relative contribution of the plants to the cover is indicated by listing them in order of decreasing importance. Thus in the area of a map unit labeled MNB, black spruce is most widespread, dwarf and/or shrub birch is of secondary importance, and paper birch is of lesser importance, but still with enough cover to have been well represented on the image. In most map units a number of other plants also occur in the overstory, but these together contribute less than around 20 percent to the cover. There is, of course, a host of plants of other species in the understory vegetation throughout a map unit area. (2) Codes indicating plants much more important than the others are underlined. Thus in a unit labeled SB, white spruce is the prevalent species, contributing 80 to 90 percent to the cover, and paper birch is a relatively minor admixture throughout the general spruce forest as scattered individuals or as small, less frequent and more or less pure stands. (3) A further item of information conveyed by some of the map unit codes is gross tree height class, tree height being a basic aspect of vegetation structure, and often relevant in vegetation dynamics and site characterization. A lower-case letter indicates trees less than around five meters tall. This allows for the identification of stands of young trees and of older trees of stunted growth form. Thus Hm identifies a map unit covering an area in which ericaceous shrubs are prevalent and there is an open-canopy or scattered occurrence of low-growing black spruce.

An exercise to demonstrate one of several possible uses of a map of this kind was conducted. The areas of all map units in which white spruce is the leading component were measured by planimeter. Table 2 gives the results. The point of this exercise is that it is worthwhile

Table 2. Total areas of highest-cover plant assemblages with white spruce (Picea glauca) as the most important component in the map-area of Figure 8.

Plant Assemblage	No. of units	Area km <sup>2</sup>	% total map area (257 km <sup>2</sup> )
S	17	4.31	1.67
SA	1	0.17	0.07
<u>SB</u>	9	11.37	4.42
SB	9	8.13	3.16
<u>SD</u>	2	0.54	0.21
SJ	1	0.21	0.08
SM	1	0.13	0.05
<u>SP</u>	8	5.31	2.07
SP	5	1.93	0.75
<u>SW</u>	1	3.00	1.16
SBM	1	0.90	0.35
<u>SMB</u>	1	2.92	1.17
SMJ	1	2.59	1.01
Smb	3	7.18	2.79
SmH	1	1.82	0.71
SmN	1	0.23	0.09
SPJ	2	1.20	0.47
<u>SPW</u>	1	1.51	0.59
Totals	65	53.45	20.82

to determine that white spruce is of primary importance in about 21 percent of the map-area, for this species is valuable for timber on many of the sites on which it grows.

PART VI. LAND-USE MAPS OF FIVE ALASKAN AREAS  
 BASED ON LANDSAT IMAGERY  
 A RESPONSE TO A USER-COMMUNITY NEED

IV A. Introduction

Land-use maps of Alaskan areas are of increasing importance with the current widespread rush into land disposition and resource exploitation. Such maps are an inventory of certain resources, and they can indicate the nature and extent of human activity. They are useful as guides in sensible planning and subsequent management. Land-use maps may help in organizing activities compatible with (1) the actual quantity or availability of a resource, (2) a natural environmental integrity in terms of natural regeneration potentials, artificial restoration possibilities and aesthetic qualities, and (3) the rational and long-range needs of the planner.

Land-use maps where little land use by man has begun, as in much of Alaska, are particularly important in the initial stages of development or exploitation. These maps emphasize vegetation, the most conspicuous feature in the landscape and the structurally and functionally most important component of ecosystems. Vegetation is of direct resource value as food, forage or timber, it is the principal element of wildlife habitats; and it is in the forefront in out-of-doors cultural, recreational and scientific activities. Vegetation is also important as an indicator. It is an integrated expression of the history of the site and of the nature of soils, drainage, permafrost, topography and small and large-scale climates. Moreover, it may indicate the nature and severity of pollution and other human disturbances. The central role of vegetation in Alaskan environmental affairs is discussed more thoroughly by Anderson (1976).

The five land-use maps presented here (Figure 1; Maps 1-5) cover Alaskan areas of particular interest to the U.S. Bureau of Indian Affairs, the agency which funded the mapping in cooperation with the National Aeronautics and Space Administration, and Doyon Ltd., the native regional corporation within whose jurisdiction the map-areas lie

(French 1972; Haynes 1975). They are essentially vegetation maps depicting very broadly defined vegetations. Although botanically coarse and of only intermediate scale, these maps provide more information than previous vegetation maps of the areas and are a step toward the production of more meaningful and useful vegetation maps in Alaska. To promote the usefulness of these maps to Doyon, Ltd., a principal vegetation resource, potentially commercial timber, is emphasized on them.

#### VI B. Methods

The maps were drawn from Landsat imagery. The reasons for using satellite imagery were (1) its availability, with widespread areal and seasonal coverage, (2) its usefulness for mapping broadly defined vegetations over large areas in a fairly short time, as had been demonstrated through the work covered in Parts II and III of this report, and (3) the lack of adequate aerial photograph coverage.

The land-use classification adopted for these maps is that of the U.S. Geological Survey for use with remote sensor data (Anderson et al 1976). Most map units are identified at level II in this system. An alternative and possibly better classification for interior Alaska is presented in Part VII.

The Landsat scenes used are listed in Table 3. They were obtained by the satellite between late summer 1972 and spring 1974. Images for mapping were 16 X 20-inch photographic enlargement prints at a scale of 1:250,000. Image selection and preparation are discussed in more detail in Parts II, III and VII. Both early spring black and white and summer simulated color-infrared images were used in conjunction with physiographic information from topographic maps (see Section VII E).

Before beginning mapping, spectral unit classes represented on the images were correlated with vegetation types through comparisons with air photos covering parts of the map-areas and similar areas in interior Alaska. Alaska Forest Inventory photos in black and white modified infrared were obtained from the U.S. Forest Service, and some small-scale color-infrared photography was obtained from the National Aeronautics

Table 3. Landsat scenes used for making land-use maps of five areas in Alaska.

AREA	EARLY SPRING BLACK & WHITE	SUMMER COLOR-IR
Katag-Grayling	1273-21370 1273-21373	1002-21321 1038-21301
North Fork Kuskokwim River	1593-21084 1593-21090 1610-21024	1342-21191 1358-21073
Purcell Mountain	1236-21303 1273-21364	1037-21240 1057-21351 1345-21353
South Fork Kuskokwim River	1574-21034	1358-21075
Tanana	1251-21135 1252-21193 1613-21192	1037-21240 1341-21130

and Space Administration and its summer 1974 U-2 aerial photography mission. In general, more information is available on air photos than is necessary for establishing or verifying the broad land-use classes distinguished at levels I and II of the USGS system.

The present land-use maps emphasize vegetations possibly containing trees of commercial size. This emphasis was added at the request of Doyon Ltd., and it serves to illustrate how land-use maps, even with coarse spatial and classificatory resolution, can be applied in land-use planning (Haynes 1975). It is noted that the present concept of commercial timber is not formal and does not consider such features as stocking, regeneration potential and accessibility. Trees suitable for both lumber and pulp production are included in the definition. Vegetations here identified as possibly containing trees of commercial size are essentially forests of considerable physical stature, recognized mostly by darkness of gray shade and favorable physiographic position. This approach does not permit positive identifications, and the mapper thought it wise to err on the side of conservatism in identifying such vegetations.

The mechanics of mapping included (1) tracing streams, lakes and other prominent landmarks onto a transparent plastic overlay of the base map, a U.S. Geological Survey topographic map, (2) positioning the overlay on an image, usually the early spring image, according to common landmarks, (3) tracing spectral units, the tentative map units, onto the overlay, (4) positioning the base map over the overlay on a light table, (5) tracing the unit boundaries on the overlay onto the base map, at the same time referring to the other image, i.e. the summer color-infrared image, and (6) identifying the map units on the basis of their spectral signatures and their physiographic positions. Activity 3 is most critical. The spatial nature of the map units is determined mostly at this stage, and decisions as to where lines should be drawn are in many cases subjective. The meaningfulness of this activity depends on familiarity with the vegetation in the map-areas and with vegetation

mapping purpose and technique (Kuchler 1967b). A refined version of this method of vegetation mapping is described in detail in Sections VII F-H.

Preliminary maps were drawn, and these were used as guides to routes of travel by light aircraft for field checking. These flights led to a few adjustments of map unit identifications. Problems and methods in the verification of maps of this sort are discussed in Section VII I.

#### VI C. The maps

The maps depict 14 land-use classes, all but one (7 2) being vegetation types of broad definition. The distribution of vegetations containing trees of possible commercial size is indicated with a c in the label and is further emphasized by crosshatching.

The maps were drawn on standard topographic maps as base maps. Therefore they depict topographic and other physiographic conditions as well as cultural features. This should make the maps easy to use, as the user can determine with some precision his actual location in the landscape.

The land-use classes and their general constitution in terms of high-cover plant species or other taxa are as follows. They are listed in numerical order by code in the USGS system.

3 1. Rangeland, Herbaceous. Rangelands dominated by graminoids, forbs, cryptogams or mixtures of these, with admixtures of shrubs

Principal species are bluejoint grass (Calamagrostis canadensis), fireweed (Epilobium angustifolium), the fescue grass Festuca altaica, squirreltail grass (Hordeum jubatum), and the wormwood Artemisia frigida. Several species of Cladonia probably occur as dominants in lichen rangelands in the Purcell Mountain area.

Unlike poorly drained nonforested wetlands, which are somewhat similar physiognomically, herbaceous rangelands occur on upland, well-drained sites. Hence they are different floristically, they lack peat accumulation, and most lack permafrost.



Some herbaceous rangelands represent early post-fire successional vegetations, with any charred plant material obscured by live plant cover. Others, particularly lichen-dominated rangelands, represent much older and more nearly steady-state vegetations.

3 1 b. Same, in recently burned area; charred vegetation still evident

Most live plants are forbs and grasses. In addition there is new growth by woody plants whose rootstocks survived the fire.

The blackness characteristic of this class is readily seen on summer Landsat imagery. Whereas live plants colonizing the burn are not yet sufficiently abundant to obscure the charred material, it is concluded that the burn was recent, probably having occurred not more than two years prior to the image date. A similar situation was immediately apparent and was verified in the work covered in Part II. Hence the few burn areas depicted on the present maps would have occurred in 1971, 1972 or earlier in 1973.

3 2. Rangeland, Shrub and Brush. Willow or alder thickets; stands of young trees; ericaceous shrub thickets or shrublands (heaths) with scattered small black spruce

Shrub rangelands are dominated by shrub species and/or shrub-sized individuals of tree species. Closer to the larger streams shrub rangelands feature willows (Salix spp.) and alders (Alnus spp.), usually as dominants in flood-plain and point-bar early successional vegetations. Similar stands occur as riparian vegetations along the numerous smaller streams. Such stands are in most cases too small to map at 1:250,000. Willow and alder shrub rangelands are widespread in the uplands in the vicinity of treeline. Elsewhere in the uplands shrub rangelands may be dominated by young aspen (Populus tremuloides) and paper birch (Betula papyrifera) in post-fire successional stands.

The most prevalent phenomenon in the shrub rangeland category, as this category is interpreted here for application in interior Alaska, is

the kind of vegetation dominated by medium-height ericaceous shrubs and shrub birch (Betula glandulosa) and featuring in addition an open or sparse layer of small but old black spruce (Picea mariana) (cf. Subsection IVD(4)). The principal species are the Labrador teas (Ledum palustre ssp. groenlandicum and L. p. ssp. decumbens), bog blueberry (Vaccinium uliginosum), shrub birch and black spruce. This kind of vegetation is widespread in interior Alaska, and it intergrades extensively with forested wetland and needleleaf evergreen forests and woodlands. Shrub rangelands characterized by broadleaf deciduous shrubs and young trees are important for wildlife, especially moose, because of their high proportion of browse food material. There is also abundant cover for smaller animals and birds.

Shrub-dominated vegetations in low-elevation, poorly drained flat areas are classified with nonforested wetlands, and shrub-dominated vegetations above the elevation of tree line are lumped with other tundra vegetations in class 8.

3 2 b. Same, in recently burned areas; charred vegetation still evident

This land-use class designates areas bearing early post-fire successional vegeta<sup>t</sup>ions of shrubs, chiefly willows or seedlings of aspen, paper birch or white spruce (Picea glauca). Charred plant material and fallen trees are abundant, and the blackness of this is apparent on the summer color imagery.

Recent-burn shrub rangelands should be valuable as wildlife habitat over the next several years as woody species become more abundantly established. Succession directly back to forest vegetation should occur in most places.

4 1. Forest, Broadleaf Deciduous. Forests dominated by paper birch, aspen, balsam poplar or mixtures of these

Paper birch is the most widespread, occurring throughout the geographic and habitat ranges of broadleaf deciduous forests. Aspen is also widespread, but occurs mostly on south and near-south slopes of

moderate steepness. Balsam poplar (Populus balsamifera ssp. balsamifera) is relatively limited in distribution, large trees occurring as stand dominants only on old flood plains in the vicinity of major streams. Most trees in broadleaf deciduous forests are of small to intermediate sizes, i.e. with breast-height diameters of 8 to 20 cm and heights of 6 to 20 m. Tree cover ranges from open-canopy, around 40 percent, to closed-canopy.

4 1 c. Same, possibly with trees of commercial size

The only broadleaf deciduous, or hardwood forests with timber potential occur as small and scattered stands on old flood plains in the vicinity of major streams. Here the chief species is balsam poplar. The commercial forests mapped in upland areas are dominated by paper birch, in closed and somewhat open stands of medium to medium-large sized trees, i.e. with breast height diameters of 15 to 30 cm and heights of 16 to 25 m. Admixtures of individuals or small stands, including clones, of aspen are frequent. These upland forests were designated commercial because they were judged to contain trees sufficiently large and abundant for pulp production.

4 2. Forest, Needleleaf Evergreen. Forests dominated by white spruce, black spruce or mixtures of these

White spruce is the dominant species in needleleaf evergreen forests on upland sites of most slopes. North slope needleleaf evergreen forests are usually dominated by black spruce in closed or open stands.

Needleleaf evergreen forests on low-lying flat areas away from major streams also are dominated by black spruce, but these are designated forested wetland, in accordance with the definition of this class in the USGS system.

4 2 c. Same, possibly with trees of commercial size

White spruce is almost exclusive as the dominant in commercial needleleaf evergreen forests. Such forests occur mostly on the flood plains, where white spruce forests with large trees usually follow

balsam poplar forests as a later stage in vegetation succession. A few upland sites of moderate slope and south to near-south aspect also bear such forests

White spruce of commercial size dominate in narrow gallery forests along the many smaller streams in the lowlands. These forests, although occurring widely, are too small areally to show on the maps.

4 3. Forest, Mixed. Forests dominated by mixtures of broadleaf deciduous and needleleaf evergreen trees

Mixed forests, with the constituent species present in widely varying proportions, are a reflection of widespread heterogeneity in environmental and historical factors.

Most mixed forests in the map-areas are dominated by trees of intermediate size or, at higher elevations, by small trees. Some of these forests are open, with low tree densities and correspondingly high shrub densities.

4 3 c. Same, possibly with trees of commercial size

As Mixed Forest is the most frequent noncommercial forest type in the map-areas, it is also the areally most important commercial forest type. Like the other two commercial types, it also occurs mostly on flood plains and lower-elevation uplands in the general vicinity of main streams. The most important broadleaf components are balsam poplar and paper birch. Aspen occurs as a lumber-sized tree only infrequently, but it may be of considerable importance for pulp. White spruce is the important needleleaf species, and in most cases this component is the only one of timber value in commercial mixed forests.

6 1. Wetland, Forested. Mostly black spruce bog woodlands

6 designates wetland, a broad land-use class covering areas where the ground-water table is at or near the surface most of the growing season. Many wetlands in the map-areas have permafrost.

6 1 designates wetlands in which the water table is just low enough, the permafrost table just deep enough, and soil drainage just mobile enough to allow some tree growth. Black spruce is most frequent, but paper birch also occurs in forested wetlands. Trees are small to

intermediate in size, and their densities are low. Hence the vegetation is commonly woodland rather than forest. Black spruce bog woodland, colloquially called muskeg, is the areally most important vegetation in this class. The bog components are shrubs, dwarfshrubs and an abundance of cryptogams. Shrubs and dwarfshrubs are several ericaceous species, shrub birch, dwarf birch (Betula nana) and some willows. The cryptogam layer is made up of several moss and lichen species, often with Sphagnum species as dominants. Herbs are widespread but of low density.

#### 6 2. Wetland, Nonforested. Bogs and marshes

Some nonforested wetlands are similar to forested wetlands except for a lack of trees. Dwarfshrubs and cryptogams dominate, and in some cases there is dominance of graminoids. The most important dwarfshrubs are several willow species, dwarf birch and the ericaceous species lowbush cranberry (Vaccinium vitis-idaea), bog blueberry, the Labrador teas, and crowberry (Empetrum nigrum). An herbaceous component may be cottongrasses (Eriophorum spp.) or sedges (Carex spp.) The cryptogam layer features a high proportion of Sphagnum spp

Nonforested wetlands with this general vegetation composition are bogs, in which there is peat accumulation and a shallow permafrost table.

Other nonforested wetlands feature different vegetations and are more appropriately designated marshes. Here the water table is at or above the surface, and the ground water is mobile. Graminoids and bryophytes are dominants, a few sedges and grass species being characteristic. In the map-areas, units labeled 6 2 located near small, slow-flowing streams and near ponds and lakes with apparent drainage in flat areas are more often marshes than bogs. Marshes are important as waterfowl habitat.

#### 7 2. Barren Land; sandy island.

#### 8. Tundra. Shrub, dwarfshrub, herbaceous and fellfield tundras

This is a broad land-use class comprising at least five major physiognomic vegetation types: Shrub Thicket, Dwarfshrub Thicket, Meadow, Fellfield and Rock Vegetation. Landsat spectral information was

not sufficient to justify an attempt to distinguish tundras at level II in the USGS system. It is likely that only mosaic units could have been mapped anyway because of the high spatial heterogeneity in physiography and vegetation in the alpine tundra zones of the map-areas. Whereas some tundras are physiognomically similar to some herbaceous and shrub rangelands and nonforested wetlands, tentative distinctions were made according to elevation. In the Tanana and North and South Fork Kuskokwim River areas, tundras were recognized above approximately 600 m (2,000 ft). In the Kaltag-Grayling and Purcell Mountain areas, they were recognized above approximately 300 m (1,000 ft). . 3

Much of the tundra zone in the map-areas is probably important as habitat for caribou, moose, sheep, bears and many bird species.

PART VII. VEGETATION MAPPING AT 1:250,000 IN INTERIOR  
ALASKA USING LANDSAT IMAGERY IN PHOTOGRAPHIC FORMAT.  
A COMPREHENSIVE DEMONSTRATION

VII A. Introduction

Most of the land in Alaska and the rest of the world is conspicuously covered with vegetation. Vegetation is a primary environmental component and natural resource, and it is a fairly reliable and useful indicator of other environmental components and resources. It is of central importance structurally through its multifarious influences on the physical environment of all organisms, including man. It is of central importance functionally through primary production and its leading role in biogeochemical cycling. Vegetation is therefore basic in ecosystem definition and delineation. It follows that land-use planners and managers and ecologists of various sorts must take vegetation into account at the outset.

The landscapes of Alaska feature diverse and complex, mostly natural vegetations of foremost aesthetic, scientific and economic interest. The number of principal life forms and species is modest, but these occur in many combinations. Most areas are occupied by a number of more or less distinct combinations, or vegetation units, of several kinds, together constituting a mosaic in the landscape.

VII A 1. Vegetation mapping

The vegetation map is a comprehensive, readily comprehensible and usable form of vegetation and other environmental information. It is therefore a basic tool in planning and management, and it can suggest hypotheses and areas needing further research. The general-purpose vegetation map is of primary importance. This portrays the distribution of defined vegetation units and perhaps principal associated environmental components, such as soil units, but does not depict any particular botanical or environmental feature.

The general-purpose vegetation map can be interpreted as a map of actual plant resources, e.g. timber and forage. In addition, the indicator value of vegetation makes possible interpreting such a map in terms of climatic conditions, parent materials, soils, permafrost, wildlife habitat, agricultural potential, and recreational areas. The vegetation map constitutes basic information for the subsequent mapping of these items. Vegetation map interpretation should be facilitated with an accompanying encyclopedic text treating each map unit class botanically and environmentally. To the extent it were available, information pertaining to vegetation function and dynamics should be included in the text. Primary production and the possible course of succession are of chief concern. The use of such a text can make the vegetation map more than a colorful wall decoration.

The general-purpose vegetation map is a fundamental kind of resource map and ought to be one of the first made. But it is not a panacea; it cannot be expected to serve a specific purpose as well as an actual map of the variable of immediate concern. Nevertheless, it can nearly always serve to some extent in the absence of other kinds of maps because of the indicator value of vegetation. It would be of interest to a larger and more diverse user community than any other single kind of resource map. These considerations are important in Alaska where special-interest agencies, such as the U.S. Forest Service, National Park Service and Soil Conservation Service, have so far been able to inventory and map only small parts of the state in desirable (for them) fashion.

The extent of vegetation mapping in Alaska is modest, as is the description, conceptual delineation and classification of vegetation types prerequisite to the spatial delineation of vegetation units in mapping. This is especially apparent vis-à-vis the current rush into land disposition and resource exploitation. Existing vegetation maps of the state (Spetzman 1963; Küchler 1967a, Viereck and Little 1972, JFSLUPCA 1973) are of small scales and depict only broadly defined vegetations. At these scales even the smallest map units cover large land areas, and it is uncertain that an indicated vegetation actually occurs at a given point in the landscape. Unfortunately, estimates of the probabilities



of such occurrences are not provided, although this should be possible through air photos or extensive field sampling.

The preceding refers to the concept of vegetation map probability. Probability estimates for each map unit class would be desirable. These could be averaged, with weighting according to the total area of each class, for an overall vegetation map probability estimate.

Even our superficial acquaintance with the spatial complexity of Alaskan vegetation indicates that at small scales vegetation map probabilities are too low for contemporary scientific and applied needs. The raising of vegetation map probabilities through mapping at larger scales is an important goal in vegetation science. On large-scale maps probabilities are higher, if not quantified, because the smaller map units represent smaller land areas. In general, vegetation diversity decreases as area decreases. The most interesting and useful products will be large-scale, high-probability maps of narrowly defined vegetations, or plant communities or associations in the formal sense (Anderson 1976).

## VII A 2. Landsat imagery applications

The Landsat system shows potential for some kinds of vegetation mapping in Alaska. The several earlier studies of the applicability of Landsat imagery in photographic format indicated that vegetation may be mapped across large areas at intermediate scales, i.e.  $1:10^5$  to  $1:10^6$ , fairly quickly and inexpensively. These studies also indicated that the maps thus produced may serve useful purposes (see Parts V and VI).

It is to be stressed that Landsat spectral information alone usually is not sufficient to identify map units in terms of vegetation types significantly narrower in definition than are represented on the existing small-scale maps. But information is abundant with respect to the spatial complexity of the broadly defined vegetations. On good Landsat enlarged photographic images spectral units appear to the unaided eye as distinct gray shades or colors. These units are relatively large and individually mappable in some places, and in others they constitute fine-scale mosaics. In still other places blends of gray shades or colors may be recognized. This complexity of spectral

signatures represents some of the spatial complexity of the vegetation in the landscape

It is possible to map somewhat more narrowly defined vegetations through the use of additional information in conjunction with Landsat spectral information. Of most importance is the physiographic information provided by topographic maps. Vegetation is partly a function of physiography, and there is some knowledge of the principal relationships between vegetation and physiography in most areas. Standard topographic maps can be used as base maps for vegetation mapping to facilitate physiographic considerations.

The use of topographic maps as base maps has the further advantage of assuring that vegetation maps depict cultural and other nonvegetation features. Many vegetation maps lack such features or show only a few and are therefore hard to use. The map user must be able to know his every location on the map, especially when using it in the field or otherwise when trying to determine the probable vegetation at a certain point in the landscape.

Vegetation is also a function of history, especially of succession following fire and physiographic disturbance. Most evidence for historical developments is obscure or nonexistent except in large-scale air photo or detailed field examinations. Therefore it usually is not possible with satellite image-based methods to interpret more than the gross nature of the vegetation currently occupying a place. In the case of fire, however, an especially important factor in interior Alaska, certain evidence may be apparent on Landsat imagery. This usually is in the form of spectral units with outstanding shapes and sharp, physiographically incongruous boundaries. On some false-color images, recent severely burned areas are readily identifiable by their blackness. This was discussed, for example, in Part II in dealing with the western Seward Peninsula image. The use of existing knowledge of post-fire vegetation ecology can promote more precise map unit identifications and some interpretations of vegetation history in the mapped area.

Machine processing of Landsat data might provide a quick initial plot or display of spectrally-based tentative map units, and perhaps

should in mapping large areas when the facilities are available. This may reduce the work of establishing tentative units, but the shape of the final map units and particularly their vegetation identifications must still be made by the mapper in consideration of the physiography and any historical evidence. Only recently has it begun to appear practicable to put some physiographic information (elevation, slope and aspect) for a few areas into a computer program along with spectral data. Climatic factors may also have to be considered, especially in large map-areas, and the job of putting climatic data into a format for processing with the other information may for some time continue to favor the judgement of a worker familiar with vegetation-climate relationships.

#### VII B. Purpose

The purpose of this part of the report is to present comprehensively a straightforward method for using Landsat imagery in photographic format in conjunction with other available information for general-purpose vegetation mapping at the intermediate scale of 1:250,000 in interior Alaska. The purpose is additionally to discuss basic philosophical and practical concerns in vegetation classification and mapping and map verification which too often are neglected by the remote-sensing community, especially that part of the community working with satellite imagery, wherein there is a widespread preoccupation with the technology of data processing and display. A more extensive treatment of these concerns was developed during the latter stages of the NASA-contracted research and is available as a separate paper (Anderson 1976). The method here demonstrated represents an integration, augmentation and refinement of the methods used to make the maps with which the preceding parts of this report have dealt. The method should be applicable at other scales, and it might be feasible in other areas.

A demonstration map is presented at the original scale (Figures 11 and 12) and enlarged to 1:63,360 (Map 6) for more appropriate labeling and greater legibility. The map-area lies just west of Fairbanks and was treated earlier in Parts III, IV and V. Materials are provided

(Figures 9, 10, 12; Table 8) with which the reader may repeat the experiment, as it were. These materials are essential to the demonstration, particularly <sup>in light of</sup> the subjective nature of the image interpretations.

The rationale for this demonstration is: (1) Good Landsat photographic images provide much potential vegetation information by way of a high diversity of spectral units, or gray shades and colors, and of complex but nonetheless visually apparent patterns of units of various kinds and sizes. (2) There are prospective users of Landsat imagery, particularly in the land-use planning and resource management fields, who lack the sophisticated and costly facilities for the automated processing and interpretation of Landsat data, and who in any case need specific procedural guidance, as in a cookbook.

By the present method it should be possible to produce vegetation maps of areas up to a few thousand square kilometers in size for only the cost of a few Landsat images, simple drafting materials, and the services of a vegetation scientist familiar with the vegetation in the map-area. The assistance of a cartographic technician would be desirable. The cost of verification would depend on the accessibility of the map-area or the availability of adequate aerial photography or other information beyond that used in initial spectral signature identification. The method probably would be practicable for large areas, i.e. over a few thousand square kilometers in size, if the initial plotting or display of spectral units, or tentative vegetation map units, could be done mechanically.

#### VII C. The map-area

The demonstration map-area lies approximately 25 km west of Fairbanks in the Yukon-Tanana upland in interior Alaska (Figure 1). It is a broad transect from the lowland flats south of the Tanana River to a small subarctic alpine area on Murphy Dome with elevations ranging from approximately 120 m to about 900 m. It is 16 x 46 km, or 660 km<sup>2</sup> in size.

It encompasses the Bonanza Creek Experimental Forest of the U.S. Forest Service and the map-areas of Parts IV and V. It is the test area dealt with in the proposal to NASA (Anderson and Van Cleve 1971)

Physiographic diversity and fires in the map-area have promoted the development of a vegetation complex believed fairly representative for interior Alaska. Several kinds of forest are most prevalent. Woodlands and bogs are of intermediate areal importance, and there also are shrub thickets, dwarf~~shrub~~ thickets, meadows, marshes and fellfields, although stands of the latter three are mostly too small and scattered to map at 1:250,000. The most important vegetation types represented in the map-area are listed in a physiognomic-floristic classification in Table 4.

Aerial photography was obtained by NASA in July 1972 along a southeast-northwest flight line through the map-area centered on the experimental forest. This is in natural color and color infrared and at scales of approximately 1:10,000 and 1:40,000. It was a source of information on the vegetation of the map-area additional to the literature and the writer's limited field knowledge, and it was the chief reference for identifying spectral signatures on the Landsat images. Some of this photography was set aside at the outset for use in vegetation map verification (Section VII I).

#### VII D. Vegetation classification

A vegetation classification is essential to vegetation mapping. A classification must be adopted, or devised if necessary, even though it may be tentative or of only local, special-purpose or ad hoc applicability. It would be futile to delineate map units without a scheme for their possible identities, based on knowledge of the vegetation. A classification is prerequisite to mapping except when delineating provisional units on a map to be used as a guide in field vegetation research and the creation of an a posteriori classification (Küchler 1967b: 31) The latter is not the approach here, nor does it very often seem to be in product-oriented research.

A two-level classification was devised by modifying one under development by Viereck (In press), which is based on that of Fosberg

(1967). The present scheme features at the primary level physiognomic classes, within which member vegetations are recognized by gross structural and leaf characters, mostly height and spacing and deciduousness, shape and texture. At the secondary level are general community types, defined by dominant taxa and/or life forms. The physiognomic classes are comparable to the Fosberg-Viereck formation classes, except for Bog, Dwarf shrub Thicket and Marsh, where equivalencies are partial and mixed. General community types here are the vegetation units in the Fosberg-Viereck classification. A few additional types (which have not been formally sampled and described) are listed here, as these also are believed areally important in the map-area.

The nine physiognomic classes represented in the map-area are listed and briefly described in several paragraphs below. The corresponding formation classes of the Fosberg-Viereck scheme are given, as are the Level II classes of the U.S. Geological Survey land use classification system for use with remote sensor data (Anderson et al 1976). Reservations regarding terminology and uncertainties regarding the proper disposition of some vegetations of interior Alaska in the USGS system precluded its use in this demonstration (see Subsection IV D (4)). However, it is of possible usefulness in Alaskan vegetation mapping, perhaps through expansion at third and fourth levels.

Whereas the present map (Figure 11 and Map 6) features only physiognomic classes, all general community types believed areally important in the map-area are listed in Table 4. This is to indicate more thoroughly the composition of and variation within the physiognomic classes. Occurrences of stands representing general community types may be predicted by considering the physiographic information in Table 5, with the latter giving the most probable choices for a given physiographic position.

Although some thought was given to the nature of this classification, especially its terminology, it is not being proposed for use beyond the purpose of serving the immediate mapping activity. Much more field work and description of vegetation units will be necessary before a more nearly ideal classification can be devised. Reference is made to work of

Table 4. A two-level physiognomic-floristic vegetation classification for the Tanana River-Murphy Dome map-area. Physiognomic classes and general plant community types within them are listed alphabetically by code. Common names are given in the Glossary.

B. Bog

D/Sp. Dwarf/Shrub/Sphagnum Bog<sup>1</sup>

Sp. Sphagnum Bog

Tg. Tussock-Graminoid Bog

D. Dwarf/Shrub Thicket

Bn/F. Betula nana/Feathermoss Dwarf/Shrub Thicket

Bn-L/C. Betula nana-Ledum/Calamagrostis Dwarf/Shrub Thicket<sup>2</sup>

Other combinations of Arctostaphylos alpina, Betula nana, Empetrum nigrum, Ledum spp., lichens, mosses, Salix spp., Vaccinium uliginosum and V. vitis-idaea.

Fb. Broadleaf Deciduous Forest

Bp/A/C. Betula papyrifera/Alnus/Calamagrostis Forest

Bp-Pt/A. Betula papyrifera-Populus tremuloides/Alnus Forest

Pb/A/E. Populus balsamifera/Alnus/Equisetum Forest

Pt/S/Au. Populus tremuloides/Salix/Arctostaphylos uva-ursi Forest

Fm. Broadleaf Deciduous-Needleleaf Evergreen Forest (Mixed Forest)

Bp-Pg/A/C. Betula papyrifera-Picea glauca/Alnus/Calamagrostis Forest

Bp-Pm/L. Betula papyrifera-Picea mariana/Ledum Forest

Pg-Pb/A/E. Picea glauca-Populus balsamifera/Alnus/Equisetum Forest

Pg-Pt/Au. Picea glauca-Populus tremuloides/Arctostaphylos uva-ursi Forest

Table 4, continued

## Fn. Needleleaf Evergreen Forest

Pg/F. Picea glauca/Feathermoss ForestPg-Pm/F. Picea glauca-P. mariana/Feathermoss ForestPm/F. Picea mariana/Feathermoss Forest

## N. Marsh

Cx. Carex Marsh

## S. Shrub Thicket

A-S/E. Alnus-Salix/Equisetum Shrub ThicketBg-Lg. Betula glandulosa-Ledum groenlandicum Shrub ThicketS/C-Ep. Salix/Calamagrostis-Epilobium Shrub Thicket

## Wm. Broadleaf Deciduous-Needleleaf Evergreen Woodland (Mixed Woodland)

Bp-Pg/Bg. Betula papyrifera-Picea glauca/Betula glandulosa WoodlandBp-Pg/S. Betula papyrifera-Picea glauca/Salix WoodlandBp-Pm/Bg. Betula papyrifera-Picea mariana/Betula glandulosa Woodland

## Wn. Needleleaf Evergreen Woodland

Pg/Bg/F. Picea glauca/Betula glandulosa/Feathermoss WoodlandPm/Cl-F. Picea mariana/Cladonia-Feathermoss WoodlandPm/Cl-Sp. Picea mariana/Cladonia-Sphagnum WoodlandPm/V/F. Picea mariana/Vaccinium/Feathermoss Woodland

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<sup>1</sup>Taxa (usually species or genera) or life forms in different vegetation layers are separated by slashes. The layers are designated in order of decreasing height.



Table 4, continued

<sup>2</sup>Taxa or lifeforms in the same layer are separated by dashes. Here the order is alphabetical, to preclude any implication of relative importance. This is in contrast to the arrangement of map unit code elements, where relative areal importance is indicated.

NB: The names of all units in this classification (and in any good and usable classification) are substantives, clearly, unambiguously and consistently. Thus one may speak of a Bog, a Dwarfshrub-Sphagnum Bog, a Mixed Forest, a Picea mariana/Cladonia-Feathermoss Woodland, etc. Frequently encountered elsewhere is the use of adjectives or adjectival word groups as the names of classification units, e.g. Closed bryoid (moss), Low shrub/Sphagnum, Closed shrub, etc. The use of substantives throughout would be more logical and might promote the learning and application of a classification.

Viereck (In press) and to some ideas on research needs in classification and related matters discussed by Anderson (1976).

The following vegetation class descriptions exemplify some of the information which should be in the encyclopedic text accompanying a vegetation map. The sequence of physiognomic classes is alphabetical by code and therefore orderly and favorable for reference.

B. Bog. Sphagnum mosses or tussock graminoids dominant; other mosses, graminoids and dwarf shrubs usually present with high secondary importances; scattered small black spruce (Picea mariana) trees in some bogs, water table at or near ground surface most or all of growing season; peat accumulation. With the exception of tussock-graminoid bogs, which may not be properly classified here, the present concept of bog is similar to that of Jeglum et al (1974). Fosberg-Viereck: Closed grass in part and Closed bryoid (moss) in part. USGS: Possibly non-forested Wetland.

D. Dwarf-shrub Thicket. Dwarf shrubs present in closed-canopy arrangement or otherwise with dominance status; mostly ericads, dwarf birch (Betula nana) and willows (Salix spp.). Fosberg-Viereck: Closed bryoid (moss) in part. USGS: Shrub and Brush Rangeland or Shrub and Brush Tundra (?). In the map-area where they are of insignificant prevalence with respect to the 1:250,000 map scale, alpine herb and cryptogam meadows, fellfield vegetations and rock-surface vegetations are grouped with dwarf-shrub thickets. If these kinds of vegetation occurred as mappably large units they would be represented in this classification as separate physiognomic classes.

Fb. Broadleaf Deciduous Forest. Paper birch, balsam poplar and/or aspen (Betula papyrifera, Populus balsamifera and/or P. tremuloides) trees in closed- or somewhat open-canopy arrangement. Fosberg-Viereck: Closed deciduous forests. USGS: Deciduous Forest Land.

Fm. Broadleaf Deciduous-Needleleaf Evergreen Forest (Mixed Forest). Same, but both kinds of trees dominating with cover values varying around equality. Fosberg-Viereck: Closed mixed forests. USGS: Mixed Forest Land.

Fn. Needleleaf Evergreen Forest. White spruce (Picea glauca) and/or black spruce (P. mariana) trees in closed- or somewhat open-canopy arrangement. Fosberg-Viereck: Closed evergreen forests. USGS: Evergreen Forest Land.

N. Marsh. Carices or other graminoids dominant; water table at or above ground surface most of growing season; little or no peat accumulation. The present concept of marsh is similar to that of Jeglum et al (1974). Fosberg-Viereck: Closed grass in part. USGS: Nonforested Wetland. (The symbol N = nass in German: wet, green, low marshy. M would be for Meadow.)

S. Shrub Thicket. Shrubs in various species combinations, including stands of young tree species of shrub size. Most shrub thickets in the map-area are made up of broadleaf species, including orthophyllous deciduous species (willows, alders, shrub birch (Betula glandulosa), paper birch and aspen) and somewhat sclerophyllous evergreen species (some ericads). Fosberg-Viereck. Closed shrub. USGS: Shrub and Brush Rangeland.

Wm. Broadleaf Deciduous-Needleleaf Evergreen Woodland (Mixed Woodland). Both kinds of trees dominating with roughly equal cover values in a very open-canopy to somewhat scattered arrangement, conspicuous closed understory of shrubs, dwarf shrubs, herbs and/or cryptogams. Fosberg-Viereck: Open mixed forests. USGS: Mixed Forest Land.

Wn. Needleleaf Evergreen Woodland. Same, with white spruce and/or black spruce in the tree layer. Some black spruce woodlands contain small larch trees (Larix laricina) as an admixture. Fosberg-Viereck: Open evergreen forests with closed lower layers. USGS: Evergreen Forest Land

## VII E. Vegetation and physiographic position

The gross physiographic position of a spectrally-based tentative vegetation map unit can be determined from the unit's location on the topographic base map. This determination may help in identifying the unit to vegetation type. Knowledge of relationships between vegetation

and physiographic position is required. General relationships may be learned from the literature and unpublished sources and, of course, through field work. The latter would be necessary for the mapper lacking adequate previously obtained information.

The most common relationships between gross physiographic position and vegetation in the Tanana River-Murphy Dome map-area and vicinity are presented in Table 5. These relationships are derived from the literature and the writer's modest firsthand knowledge of interior Alaska vegetation ecology. A table of this kind is recommended for any similar mapping activity, as it imposes some organization on a heterogeneous body of knowledge, and it is convenient for reference during mapping.

In Table 5 the physiographic positions are those which may be recognized directly on a Landsat image with the aid of a topographic map. Therefore they are not defined in terms of floodplain, poorly drained lowland, etc., for such terms imply additional descriptive and functional elements which cannot be so recognized.

Table 5 would be of little use alone, with so many possible vegetations for most physiographic positions. It is meant for use only in conjunction with the imagery, with which the choices may be readily limited. For example, in the case of an upland west-facing slope (II B in Table 5), the black and white early spring image (see below) should enable choosing a forest rather than a shrub thicket or woodland, and the color summer image (see below) should permit narrowing the possibilities further to the Needleleaf Evergreen Forest physiognomic class. Beyond this, a more detailed examination of slope angle and slope position, possibly with a large-scale topographic map, could enable a choice between vegetation characterized by white spruce or black spruce. These species' tolerances are, in most places, different with respect to soil temperature and moisture, which are largely a function of slope and aspect.

#### VII F. Scene selection and image preparation

Two Landsat images of the map-area were used. These were photographic prints made from transparencies of the kind that can be bought

Table 5. Gross physiographic positions and commonly associated vegetations in the Tanana River-Murphy Dome map-area and vicinity. Vegetation codes are as in Table 4. Under each physiographic position vegetations are listed in estimated order of decreasing correlation.

I. Broad valley bottoms and low-elevation flatlands

A. Adjacent to and near major streams on the insides of bends

(1) S: A-S/E; (2) Fb: Pb/A/E

B. Somewhat removed from major streams on the insides of bends

(1) Fb: Pb/A/E; (2) Fm: Pb-Pg/A/E; (3) Fn: Pg/F

C. At distances greater than approximately one-half kilometer from major streams, more or less on the insides of bends

(1) Fn: Pg/F; (2) Fn: Pg-Pm/F; (3) Fn: Pm/F; (4) Fm: Bp-Pm/L; (5) Wn: Pg/Bg/F; (6) Wn: Pm/V/F; (7) S: Bq-Lq; (8) B: D/Sp

D. Adjacent to and farther from major streams on the outsides of bends

Same as C, but the order would be different.

E. Near or far from major streams at elevations at least a few meters higher, as on low hills in an otherwise flat landscape and as on high banks of major streams, even near the brink

Most forest types

F. Adjacent to small streams (i.e. streams which do little eroding or depositing)

(1) Fn: Pg/F; (2) Fn: Pg-Pm/F; (3) Wn: Pg/Bg/F; (4) B: D/Sp

Table 5, continued

## II. Uplands, up to the elevation limit of trees, approximately 750 m.

## A. South and near-south slopes

(1) Fm: Bp-Pg/A/C; (2) Fb: Bp-Pt/A; (3) Fb: Bp/A/C; (4)  
 Fm: Pg-Pt/Au; (5) Fn: Pg/F; (6) Fb: Pt/S/Au; (7) S: S/C-Ep

## B. East and west slopes

Most (1) forest, (2) shrub thicket and (3) woodland types

## C. North slopes

(1) Wn: Pm/V/F; (2) Wn: Pm/Cl-Sp; (3) Wn: Pm/Cl-F; (4)  
 Wm: Bp-Pm/Bg; (5) S: Bg-L; (6) Fn: Pm/F; (7) Fm: Bp-Pm/L;  
 (8) D: Bn-L/C; (9) B: D/Sp

## D. Broad ridge crests above approximately 500 m

(1) Wn: Pm/V/F; (2) Wn: Pm/Cl-F; (3) Wn: Pg/Bg/F; (4) Wm:  
Bp-Pm/Bg; (5) Wm: Bp-Pg/Bg; (6) S: Bg-Lg; (7) D: Bn-L/C

## III. Upland slopes of any direction above approximately 750 m

Same as preceding (II D), with woodlands less frequent than shrub  
 thickets and dwarf shrub thickets.

from the Earth Resources Observation Satellite (EROS) Data Center, Sioux Falls, South Dakota. The images were printed by enlargement to the scale of the base map, a part of the Fairbanks sheet in the U.S. Geological Survey 1:250,000 topographic map series. As close as possible a scale match between an image and the base map was obtained by (1) tracing a few permanent features prominent on both the image and the map, like lakes and parts of rivers, onto white tracing paper, making distinct black lines, (2) putting the tracing onto the enlarger easel and adjusting the projected image to it and (3) replacing the tracing with photographic paper for the exposure. Enlargement prints of Landsat scenes can be bought from the EROS Data Center, but the best image-base map match can't be obtained except in the manner described.

It is noted that perfect registration between an image and the base map across the entire map-area was not obtainable owing to differential scale distortion between the image and map. A technique for dealing with this in mapping is described below (Section G).

The first of the two images, Figure 9, represents part of an early spring scene, no. 1247-20511, obtained by the satellite's multispectral scanner (MSS) over interior Alaska at approximately 1100 hours LST on March 27, 1973. This scene, printed in black and white, represents reflectances in spectral band 7 (0.8 to 1.1 micrometers).

The use of a non-growing season, late snow season scene is basic to the method. The interior Alaska landscape in early spring features a snowpack approximately one meter thick most years. The parts of plants above the snow surface at this time usually bear no snow because of the low amount of snowfall during the late winter and early spring in most years and the more frequent winds. As a consequence, areas with vegetation taller than approximately one meter appear on the image in various shades of gray depending on the amount of plant cover. Areas in which all or most of the reflectance is from snow appear nearly white, and areas in which the snow is obscured by plant cover are dark gray or black. Partial plant cover is indicated by intermediate gray shades. This was confirmed by comparisons with aerial photographs and by field observations, including a low overflight in February 1975.



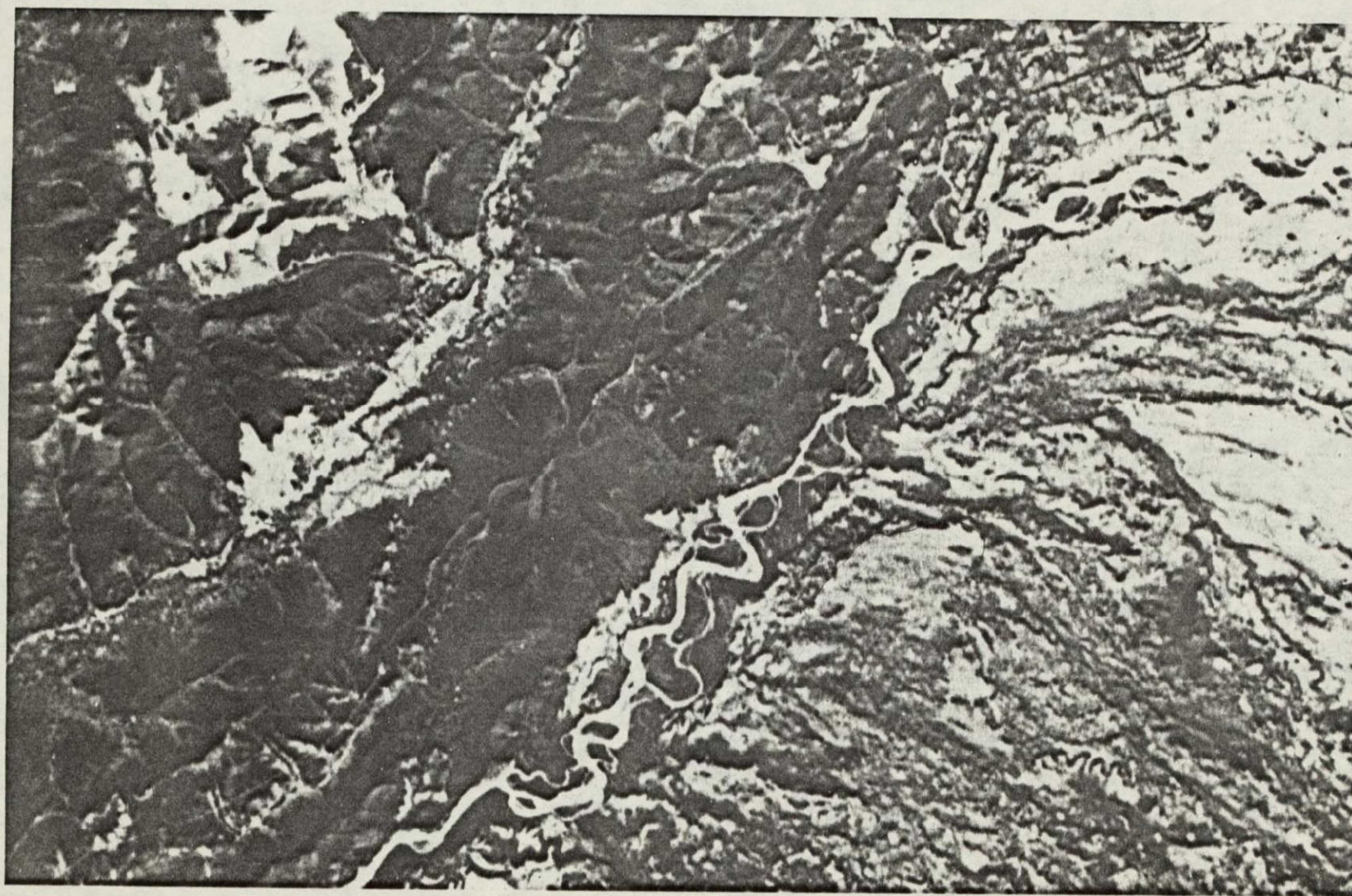


Figure 9. Part of Landsat scene 1247-20511, obtained over interior Alaska on March 27, 1973, encompassing most of the Tanana River-Murphy Dome map-area (Figures 11 and 12; Map 6). See following page.



Figure 9. Part of Landsat scene no. 1247-20511, obtained on March 27, 1973 over interior Alaska, encompassing most of the Tanana River-Murphy Dome map-area (Figures 11 and 12). Map-area boundaries were not put on this image for the reason explained in the text.

Five gray shade classes are recognized: 1 = white; 2 = light gray; 3 = intermediate gray; 4 = dark gray; 5 = black. Examples of these and of mosaic and blend combinations as recognized by the writer may be found on this image through use of the overlay in Figure 12 in conjunction with Table 8. Illustrative map units may be selected from Figure 11 and Table 8 and located here with the overlay.

This image, at a scale of approximately 1:250,000, was made from a transparency obtained from the United States National Aeronautics and Space Administration.

Table 6. Gray shade classes on the early spring Landsat image (Figure 9) and the physiognomic classes with which they were correlated. The vegetations which correlated best with a gray shade are listed first. These gray shade classes may be verified through use of Table 8 and the overlay in Figure 12.

CODE <sup>1</sup>	GRAY SHADE CLASS	PHYSIOGNOMIC CLASS
1	white	(Meadow) Marsh Bog Dwarf <del>Shrub</del> Thicket
2	light gray	Shrub Thicket Mixed Woodland Needleleaf Evergreen Woodland Dwarf <del>Shrub</del> Thicket Bog
3	medium gray	Needleleaf Evergreen Woodland Mixed Woodland Shrub Thicket Broadleaf Deciduous Forest
4	dark gray <sup>2</sup>	Broadleaf Deciduous Forest Mixed Forest Needleleaf Evergreen Forest
5	black <sup>2</sup>	Needleleaf Evergreen Forest Mixed Forest

Table 6, continued

<sup>1</sup>These codes were used for labeling on the gray shade and combination-unit overlays (see below in text). They are also used in Table 8.

<sup>2</sup>Dark grays and blacks will be seen on north slopes where the angle of incidence of solar radiation is low. These gray shades here do not necessarily indicate vegetations of abundant cover above the snow surface (see Table 5).

The early spring sun elevation at the time of day of satellite overpass in interior Alaska is high enough for this kind of remote sensing purpose. In this respect, and with respect to the usually snow-free state of all but the low-stature plants in early spring, imagery obtained earlier in the snow season, i.e., late October through February, would be less useful.

The second image, Figure 10, represents part of a summer scene, no. 1033-21011, obtained on August 25, 1972. The scene was reconstituted in simulated color infrared from MSS spectral bands 4, 5 and 7. A positive color transparency at 1:1,000,000 scale was used to make the image. The map-area part of the transparency was projected onto direct reversal color printing paper and the best scale match was obtained as with the early spring scene. Similar color reconstitutions could be made in a well-equipped darkroom by the procedure outlined in Subsection II B 2 or they could be bought from the EROS Data Center either as prints or as transparencies for local enlargement and printing.

#### VII G. Image interpretation

Spectral units constituting a continuum of gray shades, from nearly white through nearly black, appear on the early spring black and white image (Figure 9). Five gray shade classes were established, member units of which could be visually identified with reasonable consistency from one part of the image to another.

The vegetation structure variables height and cover, the chief determinants of gray shade on the early spring image, are among the key criteria in the definition of physiognomic classes. Thus rough correlations could be established between gray shades and physiognomic classes using air photos and field observations. The gray shade classes and the physiognomic classes with which they were correlated are listed in Table 6.

Six color classes were established for the summer color-infrared image, excluding the blues and blacks of water and the white of clouds. Numerous colors are apparent (Figure 10), but their grouping into a few

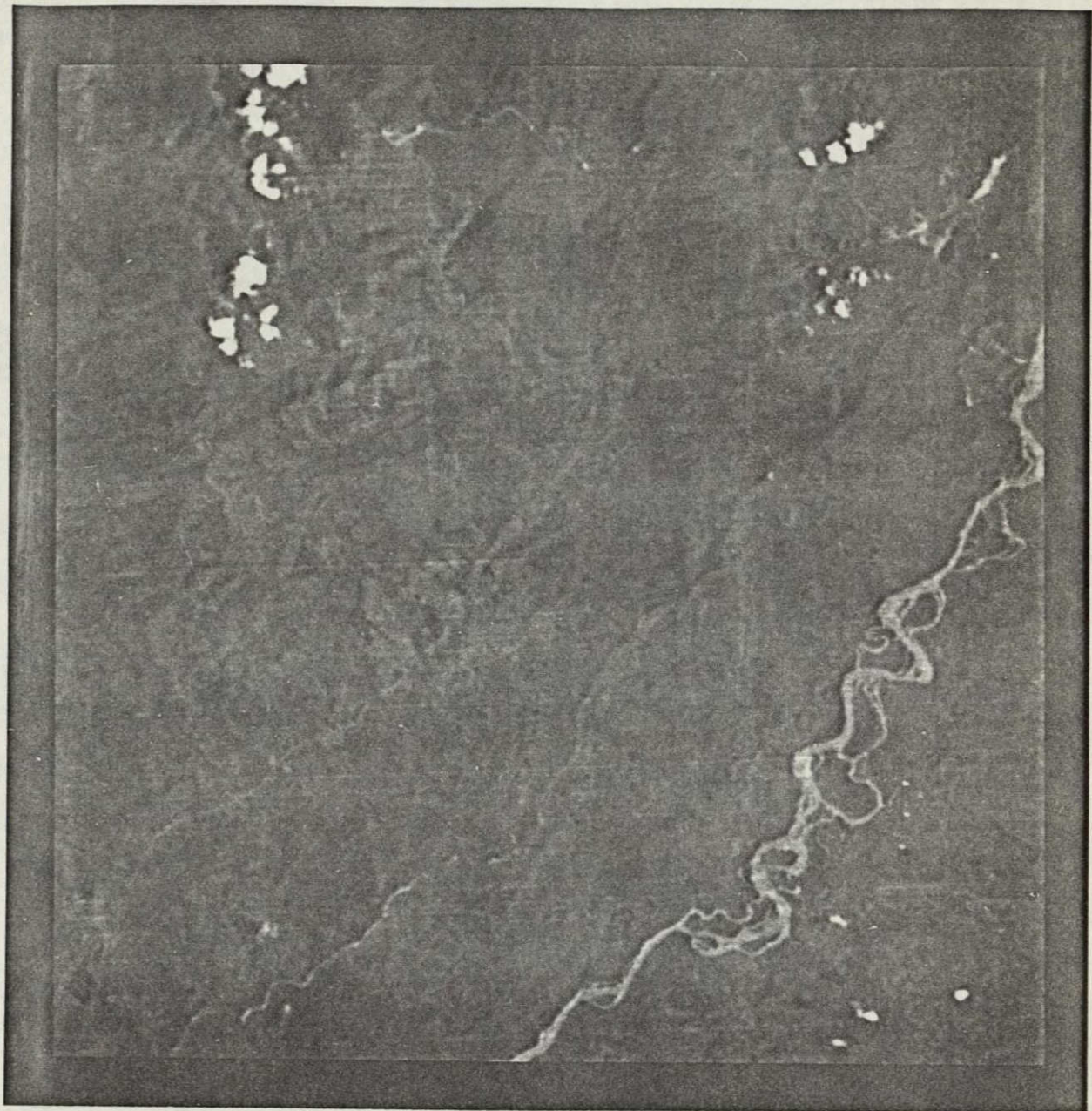


Figure 10. Part of Landsat scene 1033-21011, obtained over interior Alaska on August 25, 1972, encompassing most of the Tanana River-Murphy Dome map-area (Figures 11 and 12; Map 6). See following page.



Figure 10. Part of Landsat scene no. 1033-21011, obtained on August 25, 1972 over interior Alaska, encompassing most of the Tanana River-Murphy Dome map-area (Figures 11 and 12). Map-area boundaries were not put on this image for the reason explained in the text.

This image is in simulated color infrared, reconstituted from MSS bands 4, 5 and 7. Six color classes are recognized: D = dark gray; G = gray; L = light gray-pink; O = orange; P = pink; R = red. Examples of these and of mosaic and blend combinations as recognized by the writer may be found on this image through use of the overlay in Figure 12 in conjunction with Table 8. Illustrative map units may be selected from Figure 11 and Table 8 and located here with the overlay.

This image, at a scale of approximately 1:250,000, was made from a color transparency obtained from the United States National Aeronautics and Space Administration.

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Table 7. Color classes on the summer simulated color-infrared Landsat image (Figure 10) and the physiognomic classes with which they were correlated. The vegetations best correlated with a color are listed first. These color classes may be verified on Figure 10 through use of Table 8 and the overlay in Figure 12.

CODE <sup>1</sup>	COLOR CLASS	PHYSIOGNOMIC CLASS
D	dark gray <sup>2</sup>	Needleleaf Evergreen Forest
G	gray <sup>2</sup>	Needleleaf Evergreen Woodland
		Needleleaf Evergreen Forest
		Shrub Thicket
L	light gray-pink	Needleleaf Evergreen Woodland
		Mixed Woodland
O	orange	(Meadow)
		Dwarf Shrub Thicket
		Bog
P	pink	Shrub Thicket
		Bog
		Broadleaf Deciduous Forest
R	red	Broadleaf Deciduous Forest
		Shrub Thicket

<sup>1</sup>These codes were used for labeling the color and combination-unit overlays (see below in text). They are also used in Table 8.



Table 7, continued

<sup>2</sup>Dark grays and grays will be seen on north slopes where the angle of incidence of solar radiation is low. Vegetations not correlated with these colors elsewhere may occur here (see Table 5).



broad classes seemed to be the only way to assure consistent visual identifications from one part of the image to another. The writer assumes he has normal color vision. Vegetation correlations with the color classes were determined as for the gray shades and are listed in Table 7.

The colors occur in three kinds of units: (1) one-color units large enough to map, (2) small-unit complexes making up mappably large mosaic units and (3) units discernable only as blends of two or more colors. Gray shades also occur as pure, mosaic and blend units.

The chief importance of a color-infrared summer image is in the possibility of distinguishing (a) vegetations dominated by needleleaf trees and some broadleaf evergreen shrubs, e.g. Needleleaf Evergreen Forests and Woodlands and some Shrub Thickets, represented by gray colors, from (b) vegetations dominated by orthophyllous broadleaf plants, including Broadleaf Deciduous Forests and Woodlands and other Shrub Thickets, represented by reds and pinks. In addition, colors tending toward light orange and gray-orange represent bogs.

Thus on a simulated color-infrared image, some of the units of each of the three kinds listed above (pure, mosaic and blend units) may represent, respectively (1) vegetations dominated by one or more spectrally similar species, e.g. Broadleaf Deciduous Forests; Needleleaf Evergreen Forests, (2) vegetations comprising small, separate stands dominated by spectrally different kinds of species, e.g. small broadleaf- and needleleaf-dominated stands interspersed across the map unit area, and (3) vegetations featuring a more or less equal and uniform mixture of spectrally different kinds of plants, e.g. Broadleaf Deciduous-Needleleaf Evergreen Forests.

It is suggested that color identification charts, such as those available from the Munsell Color Company, could be used to deal more thoroughly with the multitude of different colors on a good Landsat image. However, it should by now be apparent from this demonstration and discussions elsewhere in this report that only a few color classes need be established for vegetation mapping purposes. By the method demonstrated here, a few color classes multiplied by a few gray shade classes



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multiplied by several gross physiographic positions yields a large number of possible combinations (330 in the demonstration map-area, according to the number of items listed in Tables 5, 6 and 7). The possible combinations should outnumber considerably the number of broad vegetation types represented in a map-area. The primary job for the vegetation mapper using Landsat images in photographic format is establishing correlations between vegetations actually occurring in a map-area and those fewer combinations of spectral and physiographic information representing them. Hence with the need being to assign individual color and gray-shade units to only a few broad classes, the mapper has to do no more than can accurately be done with ordinary abilities to identify and differentiate colors and gray shades.

Gray-shade and color units were traced onto separate transparent plastic overlays and labeled with the number and letter codes used in Tables 6, 7 and 8. Blend (B) and mosaic (M) units were also identified. Different colored inks were used on the two overlays (red for gray shades and green for colors).

These two overlays were superimposed in register. There was almost no spatial coincidence between gray-shade units and color units. Instead, the units overlapped in complex fashion. The reason for this is that gray shades are determined mostly by plant height, cover and leaflessness; colors are governed by leaf presence and the various life-form-specific near-infrared leaf reflectances; and these variables are expressed in numerous ways within and between vegetations and in time.

A third piece of plastic was placed over the first two registered overlays and gray shade-color combination units traced onto it. The combination units on the third overlay were labeled according to gray shade (with a number code) and color (with a letter code). The combination units were the tentative vegetation map units.

In transferring information from the superimposed gray-shade and color overlays to the combination-unit overlay, it was necessary to deal with this problem: In many places, segments of lines delineating gray-



shade and color units were only a little different in position, such that combination-unit areas encompassed by them would have been less than a reasonable minimum map unit size. Numerous undersized units, a consequence of the "noise" in the information, would have emerged had every overlap area regardless of size been strictly recognized. To preclude these, single lines were drawn on the combination-unit overlay in intermediate or "average" positions between sets of close-together gray-shade and color lines. Thus the many undersized overlap areas became parts of adjacent larger map units.

As mentioned above, it was not possible to register an image and the base map exactly across the entire map-area, even in the small Tanana River-Murphy Dome transect. In general, such registrations are probably impossible. Apparently there are slight scale differences in different directions between Landsat images and topographic maps. It is not known which more accurately represents the real spatial arrangement of things in the landscape. Perhaps both are inaccurate, differentially.

A technique was devised to accomodate this situation, that is, to facilitate the registration of the first two overlays; the delineation of spectral combination units, or tentative map units on the third; and the transfer of unit boundaries from the third overlay to the base map. The blank plastic for the gray shade overlay, and the color overlay in turn, was first put over the base map. Some of the landscape features appearing on both the base map and the image were traced onto it. Drainages and lakes were the most useful and were quick to trace. Blue ink and a fine pen tip were used. Then the overlay was moved to the image and these landscape features registered in a small subarea within which spectral unit tracing was begun. As work progressed across the map-area frequent slight shifts of the overlay provided continuous local spatial conformity. Thus, with geographic reference points derived from a common source, the first two overlays matched throughout when superimposed, and the third matched the base map exactly. With respect to the location of vegetation units, the geographic accuracy of this technique is to a



considerable extent a function of the density of common features traced onto the overlay from the base map.

It follows that the map overlay presented here as Figure 12, which is similar to the third, or combination-unit overlay discussed above, cannot at once match over an entire image (Figure 9 or 10). Instead, the reader will have to make small adjustments in going from one place to another. This situation of differential scale distortion precluded the use of fiducial marks or map-area boundary lines for immediate registration. It is recommended that the reader begin his examinations in the vicinity of the river, using it for initial registration.

#### VII H. The demonstration map

The base map was placed over the third overlay on a light table. Each tentative map unit was examined in its physiographic position, and its final identification to physiognomic class was established by considering information in Tables 5, 6 and 7 together. In most cases the tentative map units (the spectral combination units) were deemed spatially valid and were traced onto the base map as final vegetation map units. In some cases boundaries were changed or added to accommodate major physiographic boundaries and probable corresponding vegetation boundaries not apparent or missed on the imagery. In a few cases adjacent tentative map units were given the same identification following physiographic considerations, despite their different spectral signatures. These units were left separate on the 1:250,000 map (Figure 11) because by seeing them separate, the reader might appreciate more fully the impossibility of making vegetation interpretations from spectral information alone. On the 1:63,360 map (Map 6), adjacent tentative map units with the same vegetation identification were combined.

The map units were numbered, rather than labeled with vegetation codes, on the 1:250,000 map (Figures 11 and 12) to facilitate demonstrating the method. The units are identified to physiognomic class in Table 8. On the 1:63,360 map, which is intended as a usable product, the units are identified with letter vegetation codes.





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Figure 11. Vegetation map at 1:250,000 of the Tanana River-Murphy Dome area just west of Fairbanks, Alaska, based on Landsat imagery. The 208 numbered map units are identified in Table 8.

This map is too crowded for regular use. It is intended to present as much spatial information as possible at this scale, thus to demonstrate possibilities in mapping with visually interpreted imagery in photographic format. A 1:63,360 enlargement of this map with vegetation codes is in the back as Map 6.

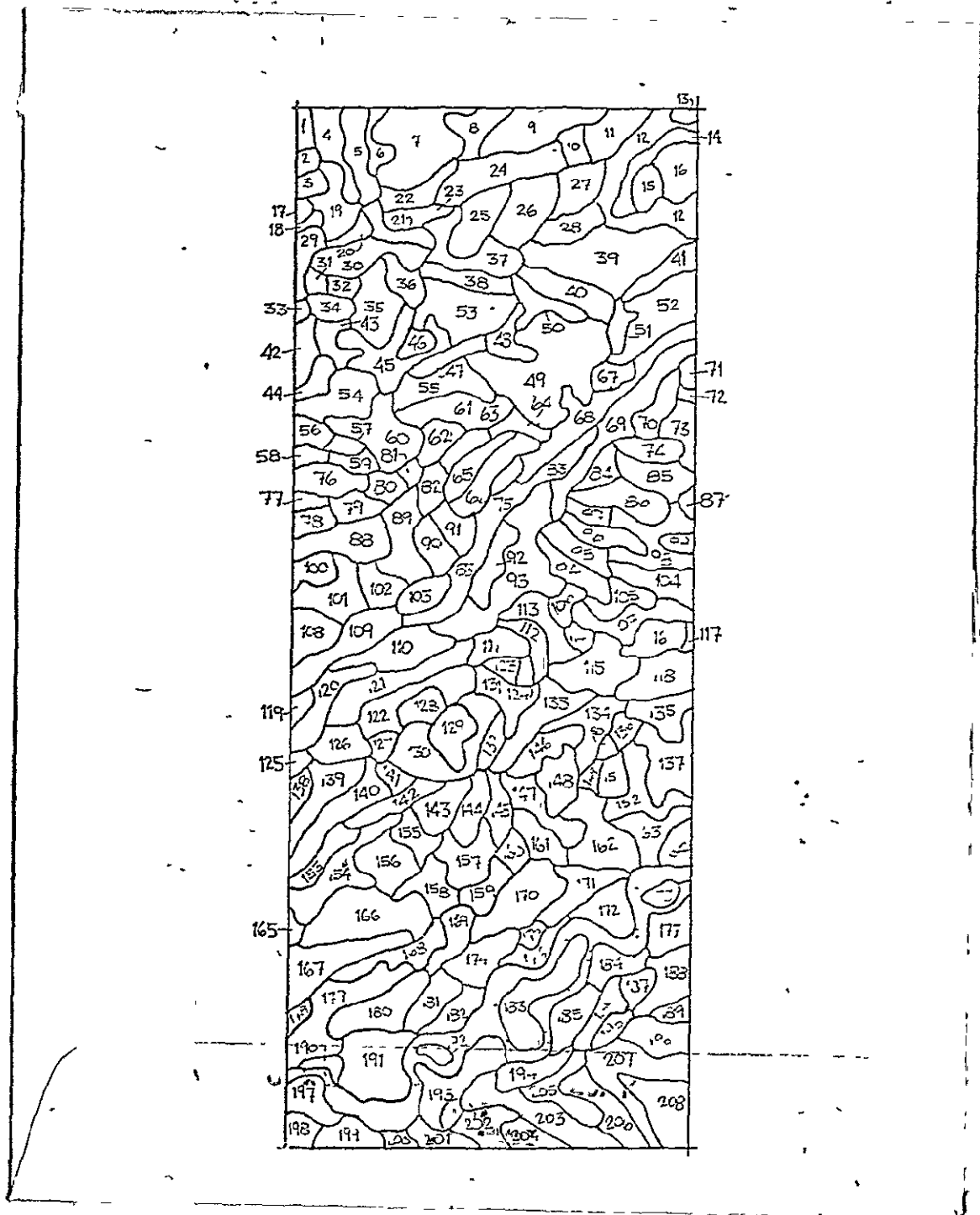


Figure 12. Transparent plastic overlay (in pocket) of the vegetation map in Figure 11. See following page.

Figure 12 (preceding page). Transparent plastic overlay (in pocket) of the vegetation map (Figure 11) which the reader may use in conjunction with Table 8 to examine the gray-shade and color interpretations made on the Landsat images (Figures 9 and 10). Any map unit may be selected and its gray shade or color noted from Table 8. What the writer saw as the noted gray shade or color may then be seen on Figure 9 or 10. However, since the map units represent combined gray-shade and color signatures, there will only be partial spatial correspondence in most cases.

This transparency will not match the images exactly because of slight scale differences between them and the map. Fiducial marks and map-area boundary lines on the images have been omitted because of this. The transparency will have to be shifted slightly from one part of an image to another in order to obtain local registration. It is recommended that examinations begin in the vicinity of the river which may be used for initial registration.

Table 8. Identifications of the 208 map units (Figures 11 and 12) according to gray shades and colors on the Landsat images (Figures 9 and 10) and physiognomic classes (Table 4). A "B" after a multiple gray shade or color code signifies blend, and an "M" signifies mosaic. Underlining marks units checked in verification. See Table 10 for those units whose original identifications were revised.

UNIT	GRAY SHADE	COLOR	VEGETATION	UNIT	GRAY SHADE	COLOR	VEGETATION
1	5-4, B	R-G, B	Fm	18	3-2, M	O	D-S
2	5-4, B	O	S-Wn	<u>19</u>	5	D-R, M	Wn-S-Fm
<u>3</u>	5-4, B	D-R, B	S-Wm	<u>20</u>	3-2, B	D-R, B	S-D
<u>4</u>	5	R-G (?)	Wn-S-Fm	21	3-2, B	O	D
<u>5</u>	3-2, M	R-G, B	S-D	<u>22</u>	3	R-G, M	Fb-Wm
<u>6</u>	5	R-G, M	Wn-Fm	<u>23</u>	4-3, M	D-R, M	S-Wn
<u>7</u>	5	G-D-R, M	Wn-S-Fb	<u>24</u>	4	R-G, M	Fb-Wn
<u>8</u>	4	G-D-R, B	Wn-S-Fm	<u>25</u>	5-4, M	D	Wn-Fn
9	5	G-D-R, B	Wn-S-Fb	<u>26</u>	5-4, M	D-G, M	Wn-Fn
10	5	R-G, M	Fb-Fn	27	5	G-R, M	Wn-Fm
11	4	R-G, M	Fb-Fn	28	4	R-G, M	S-Wn
12	4	G	Wn	29	2	R	S-D
13	4	G-R, B	Fm	<u>30</u>	1	O	S-Wn-D
14	5	G	Wn	31	2	R-G, B	S-Wn
15	5	G-R, M	Wn-Fb	<u>32</u>	3-2, M	R-G, B	D-S
16	4-5, M	R-G, B	Fm	33	1-2, B	R	S
17	5	O	S-D	<u>34</u>	1-2, B	P	S



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Table 8, continued

UNIT	GRAY SHADE	COLOR	VEGETATION	UNIT	GRAY SHADE	COLOR	VEGETATION
<u>35</u>	3-2, M	P	S	<u>57</u>	4	R-G, M	S
<u>36</u>	1	P	S-Wn	58	2	P	S
<u>37</u>	3-2, M	P-G, M	Wn-S	<u>59</u>	2	R-G, M	S
<u>38</u>	4	R-D, M	Fm-Wn	<u>60</u>	2	P-R, B	S
39	5-4, M	R-G, M	Fb-Fm	<u>61</u>	5	R-G, M	Fb-Fm
40	5-4, M	G-D, M	Wn-Fn	62	4	R-G, B	Fm
41	5	D	Wn	<u>63</u>	4-3, B	L	S
42	3-2, M	R	S	<u>64</u>	4	D-R, M	Wn
<u>43</u>	3-2, M	R-G, B	S-Wn	<u>65</u>	5	R	Fb
44	2	P-G, B	S-Wn	<u>66</u>	4	R	Fb
<u>45</u>	2	P	S	67	4	G-R, M	Fm
<u>46</u>	5	R-L, B	Fm	68	4	L-P-R, M	Wn-S
<u>47</u>	5	D	Wn-Wm	69	4-3, M	G	Fn-Wn
<u>48</u>	5	G-D, B	Wn	70	5	R	Fb
<u>49</u>	4	R	Fb	71	5	R-G, M	Fb-Fn
50	4	G-D, B	Wn	72	4	R	Fb
51	5-4, B	G-D, B	Fn	73	5	G-R, M	Fn-Fb
52	4	R	Fb	74	4	R	Fb
<u>53</u>	5	R-D, M	Fm-Wn	75	4	R-L, B	Wn-Fm
<u>54</u>	5	R-G, M	Fm	76	5	R-G, M	Fb-Fn
<u>55</u>	4	R-G, B	Fb-Fm	77	4-3, B	G-R, B	Wn-S
56	5	D-R, M	Wn-Fb	78	5	D-R, M	Fn-Fb

Table 8, continued

UNIT	GRAY SHADE	COLOR	VEGETATION	UNIT	GRAY SHADE	COLOR	VEGETATION
79	4-3, B	D	Wn	101	4	G	Wn
80	5	D	Wn	102	4-3, M	L-P, M	Wn-S
<u>81</u>	2	L-P-R, B	S-Wn	<u>103</u>	3	P-L, B	B-S
<u>82</u>	4-3, M	G	Wn-S	104	4-3, M	R	Fb-S
<u>83</u>	4-3, M	R-L, M	Fn-Wn-B	105	5	G-R, M	Fn-Fb
84	5	R	Fb	<u>106</u>	4-3, B	R	S-Wn
85	5	D-G, M	Fn	107	5-4, M	G-R, M	Fn-Fb
86	4	R	Fb	108	5-4, B	G	Wn
87	4-3, B	R	Fb-S	109	2	P-G, M	B-S
<u>88</u>	5-4, B	R	Fb-Fm	110	4-3, M	D-G, M	Fn-Wn
<u>89</u>	4-3, M	L-P-R, M	Wn-S-B	111	5	R-D, M	Fb-Fn
<u>90</u>	3-2, M	L-P-R, M	Wn-B	112	4	R	Fb
<u>91</u>	3-2, M	L-P-R, M	B-Wn	<u>113</u>	5	R	Fb-Fm
<u>92</u>	3-2, B	P	B	<u>114</u>	5	D-R, M	Fn-Fb
<u>93</u>	4-3, M	G-P, M	Wn-S	115	5-4, B	D-R, M	Fn-Fb
<u>94</u>	5	R	Fb	116	4-3, B	R	Fb-S
<u>95</u>	4-3, B	G-R, M	Wn-Fb	117	4-3, M	G	Wn
96	5	R-G, M	Fb-Fn	118	5	D-R, M	Fn-Fb
97	5	G-R, M	Fn-Fb	119	3	G-P, M	Wn-S
98	5	D	Fn	120	3	G	Wn
99	4	R	Fb	121	5	D-G, M	Fn
100	5	R-G, M	Fb-Fn	122	4	D-G, M	Fn-Wn

Table 8, continued

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UNIT	GRAY SHADE	COLOR	VEGETATION	UNIT	GRAY SHADE	COLOR	VEGETATION
123	5	G	Fn	<u>145</u>	5	D-R, B	Fn-Fm
124	4	R-D, M	Fm	<u>146</u>	5-4, B	R-G, M	Fn-Fb
125	5	D	Fn	<u>147</u>	5	R-G, M	Fm
126	3	G-P, M	Wn-S	<u>148</u>	5	D-R, B	Fn-Wn-Fm
127	5	D-G, B	Fn	<u>149</u>	4	D-R, B	Wn-S
128	5	G	Fn-Wn	<u>150</u>	4-3, B	D-R, B	Wn
<u>129</u>	5	R-D, M	Fb-Fn	<u>151</u>	5	D-R, M	Fn-Fb
<u>130</u>	5	D-R, M	Wn-Fm	152	5	R-D, M	Fb-Fn
<u>131</u>	4	G	Wn-S	153	5-4-3, B	R	Fb-S
<u>132</u>	5	R	Fb	154	5-4-3, B	G-D, B	Fn-Wn
<u>133</u>	5	D-R, M	Fn-Fm	<u>155</u>	5	D	Fb-Wn
<u>134</u>	4-3, M	R-G, B	Fm	156	5	R-G, M	Fb-Fn
135	5-4, B	R	Fb	<u>157</u>	5-4, B	D-R, M	Fb-Fn
136	4-3, M	G-R, B	Fm	158	5-4, B	R-G, M	Fb-Fm
137	5	D-R, B	Fm	<u>159</u>	5-4, B	G-D, B	Wn-Fn
138	4-3, M	D-P, M	Wn-S	<u>160</u>	5	G-D, B	Fn-Wn
139	4	D	Fn-Wn	<u>161</u>	5	D	Fn
140	5	R-D, M	Fb-Fn	<u>162</u>	4	G	Wn-Fn
141	5	R-G, M	Fm	163	3	P-L, M	S-B-Wn
<u>142</u>	4	R	Fb	164	4-3, M	G	Wn-S
<u>143</u>	4	R-G, B	Fb-Fm	165	4-5, B	G-P, B	Wn-S
<u>144</u>	5-4, B	R-G, M	Fm-Fn	166	5	R-D, M	Fb-Fn

Table 8, continued

UNIT	GRAY SHADE	COLOR	VEGETATION	UNIT	GRAY SHADE	COLOR	VEGETATION
167	4	D-G, B	Fn-Wn	188	4-3-2, M	G-R, M	Fn-S-B
168	5	D	Fn	189	3	G-P, B	Fn-S
169	5	R-G, M	Fb-Fm	190	3	R	Fb
<u>170</u>	4	G	Wn	191	5	D-R, M	Fn-Fb
<u>171</u>	2-3, M	P	B-Wn	<u>192</u>	5	R-G, B	Fm
<u>172</u>	5-4, M	D-G-R, M	Fn-Fb-S	<u>193</u>	5-4, B	D-G-R, M	Fn-Fm
173	5	D-R, M	Fn-Fb	<u>194</u>	4-3, M	G-R, M	S-Fn-B
174	2-3, M	P-L, M	Sb-B	<u>195</u>	4-3-2, M	D-P, B	Fn-B
<u>175</u>	2-3, B	G-R, M	S-N	<u>196</u>	4-3-2, B	R	Sb-Fb-B
<u>176</u>	4-5, M	D-G, M	Fn	197	5	D-R, B	Fm
177	5	G	Fn	198	4	G-R, B	Fn-S
178	4-5, B	G-R, M	Fn-Fb	199	3	P-G, M	Sb-B-Fn
179	5	R	Fb	200	5	D	Fn
180	4	R	Fb	201	2	D	B
<u>181</u>	2-3, M	G-D, M	S-Wn-B	<u>202</u>	4-3, M	G-P, M	Wn-Fn-S
<u>182</u>	5-4, M	G-D, M	Fn	<u>203</u>	5-4, B	G	Wn
<u>183</u>	5-4, M	D-R, M	Fn-Fb	<u>204</u>	4-3, B	P-G, M	S-Fn
<u>184</u>	5-4, B	D-P, B	Wn-Fn-S	<u>205</u>	3-2, B	R-P-G, B	S-B
<u>185</u>	5-4, B	D	Fn	<u>206</u>	4-3-2, M	R-P-G, S	S-Fn-B
<u>186</u>	3-2, M	D-P, M	Wn-B	<u>207</u>	4-3-2, M	G-P, M	Fn-S-B
<u>187</u>	3-2, B	G-P, B	Wn-B-S	<u>208</u>	4-3-2, B	P	S-B

The numbering of vegetation map units in Figure 11 was for relating them to gray shade and color as well as vegetation. Obviously, codes for all three would not have fit into most of the 1:250,000 map units, at least not without obscuring the background information. Multiple vegetation codes alone would not have fit some of the smaller units. All identification needs are met in Table 8.

The reader may use the overlay (Figure 12) in conjunction with Table 8 to locate a map unit on either image to see for himself the spectral units as recognized by the writer. It must be remembered, however, that only a partial spatial correspondence can be obtained in most cases, because the final map units represent combinations of overlapping parts of gray shade and color units.

The 1:250,000 map (Figure 11) shows two small rectangles, one just east of center in the south and one somewhat west of center in the north. These are the positions of 1:10,000-scale color-infrared aerial photographs, two of a series of overlapping photos along the flight line spanning the map-area. The photos in this series were a primary source of information about the vegetation of the map-area and for identifying spectral signatures. Whereas they are not reproduced here because of the prohibitive cost, it is noted that these two photos are particularly illustrative. They show readily identifiable stands representing the most common physiognomic classes, and the vegetation boundaries on them correspond well with the boundaries on the map. This nice correspondence was recognized only after the map had been drawn.

The 1:63,360 map is labeled with vegetation codes, one code per map unit except for a few large units with repeated codes. The codes were put as close as possible to the unit centers without obscuring information on the base map. It will be seen that the codes denote the physiognomic classes in logical fashion (e.g. Fn = Forest, needleleaf evergreen), and they therefore can be readily learned.

There seemed to be no need either to color the map units or to distinguish them with crosshatching, stippling, etc. The map is legible without such devices, otherwise common on vegetation maps. These

devices would have the disadvantages here of (1) being time-consuming to apply and (2) obscuring the background information on the base map. In addition (3) colored maps are much more costly to reproduce. The writer has to use the cheaper methods of reproduction, e.g. Xeroxing. In any case, map unit coloring and patterning is necessary only when the information to be presented is too much for a compact code, or when special features are to be visually emphasized, as on the maps in Part VI.

### VII I. Verification

The validity or degree of correctness of a vegetation map, or how well it represents the vegetation in the landscape, may be evaluated through the process of verification. A useful result of verification is a percentage estimate indicating the extent to which the map units are correctly identified. A figure exceeding 85 percent is considered respectable for a satellite image-based vegetation map of intermediate scale, like the map demonstrated here. The misidentified sample map units can be revised during verification, thereby increasing the map's final overall correctness.

Verification is accomplished by checking sample map unit identities against information additional to that used in mapping. Such information may comprise larger-scale or otherwise more informative aerial photography or field observations and measurements. Information for verification is usually obtained after the best possible map has been made with available information, using this provisional map as a guide in planning sample air photo missions or field programs including low-observation overflights. Additional preexisting information discovered only after mapping can be useful too.

Verification may be accomplished by ignoring part of the available information prior to and during mapping, using it, as "additional information", only later for checking map units in a sample area, an area corresponding to the coverage of the selected information. This technique is feasible only when the information not set aside is sufficient

for spectral signature identification and any other necessary purposes. This technique was employed in mapping the Tanana River-Murphy Dome area. An abundance of high-quality air photos were available, some of which could be set aside to obviate needs for time-consuming post-mapping field checking or an expensive additional air photo mission.

In general, the nature and extent of the effort necessary in vegetation map verification depends on the map scale and the breadth of definition of the vegetation classes. Small-scale maps of large areas depicting very broadly defined vegetations may be verified comparatively easily through the use of additional small-scale air photos or by making overflights of selected parts of the map-area. Intermediate-scale maps depicting vegetations of somewhat narrower definition may be verified through lower and slower overflights and the use of more informative air photos. Such photography might feature a larger scale, better resolution, different spectral character, or additional areal coverage. Intermediate-scale maps might also be verified by gross observations of the kind that can be made by the discerning vegetation scientist looking across the landscape from a vantage point. Field observations within the vegetation involving more or less quantitative measurements may be used in verifying intermediate-scale maps, but the benefit/cost ratio vis-à-vis the immediate purpose would be low.

Preexisting large-scale vegetation maps of parts of smaller-scale map-areas may be used in verification. However, all such maps should have been brought to bear at the outset so that the smaller-scale map could have been made to represent as nearly as possible a synthesis of available detailed information.

Large-scale maps, 1:63,360 or larger, of broadly defined vegetations based on Landsat imagery, including the 1:63,360 map presented here, may also be verified with the more highly informative photography. On the other hand, large-scale maps of narrowly defined plant communities would require field work for verification.

Some readers will contend that any vegetation map can be verified only through field work. This is not necessarily so. In the case of

small-scale and all but the higher-resolution intermediate-scale maps, an adequate field program would be too costly and time-consuming compared with the use of air photos. (An obvious exception would be a tiny map of a small area.) Moreover, field work would be superfluous, except in the absence of air photos. On small- and intermediate-scale maps the units cover large areas and depict only the most prevalent vegetations. A square unit as small as one fourth of an inch on a side, for example, would represent 640 acres at 1:250,000. Many places, some perhaps of difficult access, would have to be visited on the ground before the prevailing, or average vegetation could be determined for most map units. When standing in a vegetation, especially a forest, woodland or shrub thicket, one's view is limited. Much ground would have to be covered to develop a perspective compatible with the areal extent of most units on small- and intermediate-scale maps.

Furthermore, the vegetations depicted on small-scale and many intermediate-scale maps usually are defined only by high-cover lifeforms or taxa in the overstory. In Alaska, where the number of kinds of high-cover plants is fairly small, assemblages of these in the overstory can be readily recognized on air photos. It is in this respect that field work would be superfluous for the immediate purpose of verification.

Reference here is only to post-mapping field work for verification. Any vegetation mapping effort may require earlier field work for obtaining the necessary basic knowledge of the vegetation and its ecology. This is especially so with respect to unstudied areas. It is also recognized that post-mapping field work can supplement any verification process and that it may serve various other related, secondary or future purposes in vegetation science.

As indicated above, a subset of some of the good aerial photography already on hand was put aside for use in verification of the Tanana River-Murphy Dome map. This photography is in natural color at a scale of approximately 1:40,000 in a nine-inch transparency format. It was obtained along the same flight line at the same time as the larger-scale color and color-infrared photography used earlier. With its smaller



scale it covers a larger area than the 1:10,000-scale photography, approximately 59 percent of the map-area. The 97 map units wholly or mostly covered by this photography are 47 percent of the 208 map units. Thus a fairly large sample was available, probably larger than would be necessary or possible in a normal vegetation mapping activity.

A map unit identification code may be found correct when the vegetation it signifies is identified on an air photo, or it may be found to be more or less incorrect. There are degrees of correctness or incorrectness, as the following explains. A map unit code may consist of one, two or three elements, each designating a physiognomic class of vegetation with significant areal representation in the unit area. A code element may signify any one of the nine physiognomic classes (Table 4, Map 6). In a multiple-element code various orders are possible, only one of which can indicate the order of decreasing areal importance. Furthermore, an element may indicate a physiognomic class similar to or quite different from the correct one. The misidentification of Wn as Fn, for example, would not be as serious as misidentifying Wn as Fb, D, etc.

The possible combinations and permutations of code elements are numerous, even taking only two or three at a time. Hence there are numerous possible codes for any one map unit, varying considerably in degree of correctness. The correctness of a vegetation map is not a straightforward matter of right versus wrong units.

It would not be feasible or necessary to list all the possible codes, or ways in which a unit might be misidentified. Most forms are improbable, in that the identification of map units was not at random, nor is the distribution of vegetations in the landscape a random function. Instead, the 26 incorrect or partially incorrect identifications in the verification sample area were grouped into six error classes, listed in Table 9.

The verification process should be on as nearly quantitative a basis as possible. To achieve this, the error classes in Table 9 were ranked according to how much different from correctness they are. A five-step scale was established with 0 = completely wrong and 4 = all

Table 9. Kinds of map unit identification errors and their ranks according to departure from correctness. Map units for which all important vegetations, up to three, were identified correctly in order of decreasing areal importance were rated 4.

KIND OF IDENTIFICATION ERROR	RANK
Most important vegetation correctly identified; important secondary vegetation misidentified or omitted. E.g. unit 6: Wn-Fb vs. Wn-Fm	3
Areally important vegetations identified, but in slightly incorrect order. E.g. unit 206: S-B-Fn vs. S-Fn-B	3
Areally important vegetations identified, but in very incorrect order. E.g. unit 3: Wm-S vs. S-Wm	2
Areally most important vegetation omitted or misidentified; important secondary vegetation correctly identified. E.g. unit 202: Fn-S vs. Wn-Fn-S	2
Only one of two or three important vegetations correctly identified, and this is wrong position. E.g. unit 81: Wn-B vs. S-Wn	1
No correct code elements. E.g. unit 4: Wm vs. Wn-S-Fm	0

right. With this scale each sample area map unit code was rated for degree of correctness.

Ninety-seven map units lay wholly or mostly within the area of verification air photo coverage and could thereby be checked and rated. Map units originally identified incorrectly are listed in Table 10, which gives the original identification and the degree of correctness rating for each. The revised codes are also given here for comparison. In Table 8, only revised map unit codes are given for the 27 originally misidentified units, and only the revised identifications are presented on the 1:63,360 map.

Table 11 gives the frequency distribution of sample unit correctness ratings, with the latter on a percentage basis. The product sum of Table 11 was divided by 97, the number of sample map units, and the quotient multiplied by 100 to obtain the estimate of 89.5 percent for the degree of correctness of the map.

This figure, 89.5, is an expression of the extent to which the map units were correctly identified on the map. It is only roughly comparable to a simple percentage figure for wrong versus right units. Its meaning may be better established as future maps are verified according to this process.

With the air photo-based revisions, the final map (Figure 11 with Table 8; Map 6) is presumably 100 percent correct in the sample area, making it 97.6 percent correct overall. This estimate was obtained through the calculation

$$\frac{100 \times 97}{89.5 \times 111} \times 100 = 97.6$$

where 97 is the number of units now correctly identified in the sample area and 111 is the number of remaining units, estimated to be 89.5 percent correct.

It is proposed that 89.5 percent is a more important statistic than 97.6 percent. This is because 89.5 is a measure of the accuracy that

Table 10. Original and revised map unit identifications based on sample area air photo examination.

UNIT NUMBER	ORIGINAL ID.	REVISED ID.	CORRECTNESS RATING
3	Wm-S	S-Wm	2
4	Wm	Wn-S-Fm	0
6	Wn-Fb	Wn-Fm	3
8	Wn-S-Fb	Wn-S-Fm	3
19	Wn-S	Wn-S-Fm	3
23	Wn-S	S-Wn	3
30	S-D	S-Wn-D	3
36	S	S-Wn	3
37	S-Wn	Sn-S	2
47	Wn	Wn-Wm	3
54	Fb-Fm	Fm	3
57	Fb-Wn	S	0
81	Wn-B	S-Wn	1
88	Fb	Fb-Fm	2
91	Wn-B	B-Wn	3
113	Fb	Fb-Fm	3
144	Fm	Fm-Fn	3
146	Fb-Fn	Fn-Fb	3
155	Fb-Fn	Fb-Wn	3
157	Fm	Fb-Fn	3
171	B	B-Wn	2

Table 10, continued

UNIT NUMBER	ORIGINAL ID.	REVISED ID.	CORRECTNESS RATING
181	S-Wn	S-Wn-B	3
186	Fn-B	Wn-B	3
202	Fn-S	Wn-Fn-S	2
203	Fn	Wn	2
205	S-B-Fn	S-B	3
206	S-B-Fn	S-Fn-B	3

Table 11. Frequency distribution of sample map unit correctness ratings,  
with the ratings converted to a percentage basis.

RATING	NUMBER OF UNITS	PRODUCT
1.00 (4)	70	70.0
0.75 (3)	18	13.5
0.50 (2)	6	3.0
0.25 (1)	1	0.25
0.00 (0)	2	<u>0.00</u>
	PRODUCT SUM:	86.75

physiognomic classes, as defined here, can be mapped using Landsat imagery in photographic format in conjunction with physiographic information and modest field knowledge of the vegetation.

This is not to say that the probability of encountering a mapped vegetation at a random point in the area of a unit is 89.5 or 97.6 percent. This is because only the one, two or three most prevalent vegetations in each unit are identified. Other kinds of vegetation also occur, and together these may occupy a significant portion of the landscape in a unit area, perhaps up to 25 percent of the area. With reference to the concept of vegetation map probability mentioned earlier, an estimate is not being presented at this time. It is likely, however, that the probability for the present map is higher than for any others in interior Alaska of 1:250,000 and smaller scales. This is because of the present map's comparatively high spatial resolution, or small average map unit size, and its respectably high correctness estimate.

## VII J. Summary

Vegetation is one of the most important environmental components because of its prevalence, its direct resource values, and its potential role as an indicator of other environmental components and resources. The vegetation of Alaska is diverse and complex and of foremost aesthetic, scientific and applied interest.

Vegetation and other environmental information may be presented comprehensively on general-purpose vegetation maps. Such maps, accompanied by encyclopedic explanatory texts, may be used by ecologists and land-use planners and managers for interpreting the conditions or variables of immediate interest. Then general-purpose vegetation map is not a panacea, but it is a fundamental kind of resource map and ought to be one of the first made (see Anderson 1976).

General-purpose vegetation maps of useful scale, incorporating botanically sound classifications, are needed in Alaska to facilitate decisions during the rush into land disposition and resource exploitation.

The Landsat system shows promise for vegetation mapping at small and intermediate scales in Alaska. Landsat imagery is readily usable

for visual analysis in photographic format, although mechanical processing in the initial stages probably would be necessary for mapping large areas.

The purpose of Part VII of this report has been to present a method for vegetation mapping at the intermediate scale of 1:250,000 in interior Alaska using Landsat imagery in photographic format in conjunction with available topographic maps and knowledge of the vegetation and its ecology. The presentation uses a 660 km<sup>2</sup> demonstration map-area just west of Fairbanks. It includes supporting commentary on vegetation classification, vegetation ecology, purpose and method in vegetation mapping, and vegetation map verification.

The importance of vegetation classification for mapping is emphasized. A two-level physiognomic-floristic classification is presented to serve the immediate mapping purpose (Table 4).

The importance of knowing vegetation-physiographic relationships is discussed. General correlations between vegetations and gross physiographic positions in the map-area are presented in tabular form (Table 5).

Early spring black and white and summer simulated color-infrared Landsat images were used and are provided with this paper (Figures 9 and 10). Together these display a considerable amount of potential information on the physiognomy and composition of the vegetation. A method is described for combining spectral information from the two images for delineating tentative vegetation map units.

The identification of spectrally-based tentative vegetation map units to vegetation type requires correlations between spectral signatures (recognized in five gray shade and six color classes) and vegetations (Tables 6 and 7). These correlations must be considered in conjunction with correlations with physiographic positions. The delineation on the base map and identification with letter codes of the final vegetation map units is explained.

A means is provided (Figure 12; Table 8) by which the reader may check the gray-shade and color classes recognized by the writer on the Landsat images.



Whereas the demonstration map at 1:250,000 shows considerable spatial detail and is too crowded for regular use, an enlarged version at 1:63,360 is also presented (Map 6).

The demonstration vegetation map was verified through the use of air photos covering about 60 percent of the map-area. The map was thus found to be 89.5 percent correct.

The concept of vegetation map probabilities is mentioned but not developed in this report. It is emphasized that map probabilities and map correctness, which is developed, are different. Although not determined for the demonstration map, probabilities for its units should be higher than for existing maps at similar scales in interior Alaska. This is because of the greater spatial and somewhat finer classificatory detail shown on it, and because of its <sup>s</sup>respectably high correctness estimate of 89.5 percent.

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## GLOSSARY

Brief definitions of geobotanical terms as used in this report

ALDER Alnus Mill.

ALPINE BEARBERRY Arctostaphylos alpina (L.) Spreng.

ASPEN Populus tremuloides Michx.

ASSOCIATION a vegetation of definite floristic composition and uniform physiognomy interacting with a certain combination of environmental factors.

BALSAM POPLAR Populus balsamifera L. ssp. balsamifera

BASE MAP any preexisting or specially made map, as a simple outline map or a U.S. Geological Survey topographic map, upon which vegetation units are delineated and labeled to produce a vegetation map.

BLACK COTTONWOOD Populus balsamifera L. ssp. trichocarpa (Torr. & Gray) Hult.

BLACK SPRUCE Picea mariana (Mill.) Britt., Sterns & Pogg.

BLUEJOINT GRASS Calamagrostis Adans. Mostly C. canadensis (Michx.) Beauv.

BOG a vegetation featuring low-stature plants and a cool organic soil perennially wet with ground water of little mobility. In Alaska, bog vegetations consist of mosses, with sphagna of high importance in many cases, and variable mixtures of dwarf shrubs, graminoids and lichens. Permafrost is close to the surface, soils are acid in many cases, and there is peat accumulation.

BOG BLUEBERRY Vaccinium uliginosum L.

BROADLY DEFINED VEGETATION a vegetation recognized only by its most prominent taxa or life form<sup>(s)</sup> and/or an outstanding

environmental feature, e.g. Needleleaf Evergreen Forest; Graminoid Marsh. Composition, structure and environmental relationships may vary considerably throughout a broadly defined vegetation.

BRYOPHYTES Musci (true mosses) and Hepaticae (liverworts)

CARICES sedges

COTTONGRASSES Eriophorum L.

CORRECTNESS ESTIMATE See vegetation map correctness.

CROWBERRY Empetrum nigrum L.

CRYPTOGAM a plant reproducing other than by seeds, i.e. by spores and/or asexual means. In this report cryptogams refer to the thallophytes mosses and lichens.

DOMINANT taxon or life form of greatest importance in a vegetation by virtue of height, cover and/or mass.

DRYAS Dryas L.

DWARF SHRUB woody plant less than c 0.5 m tall at normal maturity.

ERICAD plant representing the Ericaceae (heath family)

FEATHERMOSS mostly Hylocomium splendens (Hedw.) B.S.G. and Pleurozium Schreberi (Brid.) Mitt.

FELLFIELD sparse vegetation of low-stature plants and a very coarse-grained and freely drained substrate with minor soil development, mostly in tundra regions.

FIREWEED Epilobium angustifolium L.

FORB a nonwoody self-supporting dictyledonous flowering plant, e.g. fireweed.

FOREST a vegetation dominated by trees providing a closed or somewhat open canopy, thus being responsible for all or most of the spectral reflectance.

FORMATION a physiognomically distinct regional vegetation associated with a regional climate.

**GENERAL-PURPOSE VEGETATION MAP** a vegetation map providing complete coverage in the map-area, depicting units in a general-purpose classification based on standardized physiognomic, floristic and environmental criteria. General-purpose vegetation maps are potentially more widely applicable in environmental affairs than other kinds of resource maps because of the indicator value of vegetation. They can be interpreted for a variety of purposes to the extent that vegetation-indicator knowledge is available, preferably in an accompanying encyclopedic text.

**GRAMINOID** a nonwoody flowering plant with grass-like leaves, including grasses and sedges.

**GRASS** Gramineae

**GREEN ALDER** Alnus crispa (Ait.) Pursh ssp. crispa

**GROWTH FORM** the physical nature of an individual plant which may or may not correspond to the species' life form (qq.v.) depending on age and local environment; the physiognomy of an individual.

**HERB** a nonwoody self-supporting vascular plant. The category comprises graminoids, forbs and vascular cryptogams.

**HORSETAIL** Equisetum L.

**IMAGE** a Landsat scene (qq.v.) or a photographic or mechanically or electronically produced product derived from a scene used for making interpretations of vegetation or other landscape components.

**LABRADOR TEA** Ledum palustre L. ssp. groenlandicum (Oeder) Hult. and (dwarf labrador tea) L. p. ssp. decumbens (Ait.) Hult.

**LARCH** Larix laricina (Du Roi) K. Koch

**LIFE FORM** the normal growth form of a species, exhibiting major structural and functional adaptations to climate. Tree, shrub, tussock graminoid, etc. are major life form categories.

LOWBUSH CRANBERRY Vaccinium vitis-idaea L.

MARSH a vegetation featuring low- to medium-stature herbaceous plants and a soil wet most or all of the growing season with mobile ground water. Many marshes feature graminoids, particularly sedges. Some are dominated by forbs. Some have a secondary layer of abundant mosses. The water table is at or above the ground surface most or all of the time in many marshes. The soil is more or less organic, and permafrost is deep or lacking.

MEADOW a vegetation featuring herbaceous plants and a freely drained soil of a moderate or high temperature for the climate and a low or intermediate amount of organic matter. Moisture retention for plant growth in meadows ranges from considerable (wet meadows) through moderate (mesic meadows) to scarce (dry meadows).

MOUNTAIN HEMLOCK Tsuga Mertensiana (Bong.) Sarg.

MSS Multispectral scanner

ORTHOPHYLLOUS (adj.) of leaves of normal texture and shape  
e.g. of birch and aspen leaves.

PALUDIFICATION a development, under a constant climate in many cases, toward wetness in the vegetation-soil complex, involving peat formation, increasing soil moisture and acidity, decreasing soil temperatures, and corresponding floristic shifts. The change from forest to bog is a common example.

PAPER BIRCH Betula papyrifera Marsh.

PHYSIOGNOMY the appearance of vegetation, determined mostly by the growth forms of the dominant plants.

PHYSIOGRAPHIC POSITION the place in the landscape of a vegetation in terms of topography (elevation, slope and aspect), proximity to streams and lakes, position on slope, and proximity to ridge crests and peaks. This limited definition is based only on information available from Landsat images and topographic maps

PHYTOCOENOSE a plant community (qq.v.).

PLANT COMMUNITY an assemblage of plants defined according to any <sup>of a</sup> number of floristic, life form, structural and ecologic criteria. The class term is plant community type (equivalent to phytocoenose type; phytocoenon). An association is a narrowly defined kind of community based principally on floristic criteria.

RANGELAND an area featuring a vegetation of plants subject to a significant amount of herbivory, including shrubs, graminoids, forbs or certain thallophytes. The term applies mostly to the domains of grazing animals. It covers a very wide variety of vegetations and environments and is therefore of little value as a vegetation or ecosystem term. It has some utility in the area of applied vegetation science concerned with wildlife management.

RED ALDER Alnus oregona Nutt.

ROCK-SURFACE VEGETATION a vegetation consisting almost exclusively of lichens and certain mosses growing on solid rock surfaces, as on boulders and outcrops, mostly in tundra, especially alpine tundra, regions. Plant cover is complete in many cases.

SCALE the ratio of any distance on a map to the equivalent distance in the landscape by the same unit of measure. Vegetation maps are categorized by scale for convenience as follows. VERY SMALL  $\leq 1:10^7$ ; SMALL  $1:10^6$ - $1:10^7$ ; INTERMEDIATE  $1:10^5$ - $1:10^6$ ; LARGE  $1:10^4$ - $1:10^5$ ; VERY LARGE  $\geq 1:10^4$ .

SCENE the spectral information for a single MSS scan in one or, in composite products, more bands, in photographic or digital tape format.

SCLEROPHYLLOUS (adj.) of leaves which have a hard, stiff or leathery texture, e.g. spruce and Labrador tea leaves.

SEDGE Carex L.

SHRUB a normally multiple-stemmed self-supporting woody plant between 0.5 and 3 m tall at maturity

SHRUB BIRCH Betula glandulosa Michx.

SHRUBLAND a vegetation analagous to woodland (qq.v.), with shrubs instead of trees in the upper layer.

SHRUB THICKET a vegetation analagous to forest (qq.v.), with shrubs instead of trees in the upper layer.

SITE the set of abiotic factors with which a plant or a vegetation is associated.

SITKA SPRUCE Picea sitchensis (Bong.) Carr.

STRUCTURE the vertical and horizontal arrangement of plants and plant parts in a vegetation and a primary element of physiognomy. Structural characters include height, stratification, cover, density, etc. The term is often used to refer additionally to the arrangement of vegetation components, e.g. leaves, in time.

TAXON any category in an idiotaxonomic system, e.g. species, genus, class, etc.; the plants in such a category, e.g. black spruce, birches, mosses.

TENTATIVE VEGETATION MAP UNIT a map unit based on one or more spectral units which is a candidate for a vegetation map unit by virtue of spectral signature-vegetation correlations. Evaluation of candidacy involves examining the physiographic position of the unit and any other ecological information which may be brought to bear. The tentative unit may be found acceptable, or its boundaries may have to be modified to form the final vegetation map unit.

THINLEAF ALDER Alnus incana (L.) Moench ssp. tenuifolia (Nutt.) Breitung.

TUNDRA (noun) a landscape or ecosystem of local to regional extent whose climate is cool-wet-windy or cold, less wet or dry and more or less windy; whose soils are cold and little developed, and whose vegetation lacks trees and tall shrubs. Tundra is not vegetation per se. (adj.) designating a tundra landscape or

ecosystem or a component thereof, e.g. tundra flora, tundra vegetation, tundra fauna, or tundra meadow, tundra bog, etc. Arctic or alpine tundras or tundra phenomena may be specified.

**TUSsock GRAMINOID** a graminoid plant or plant complex forming a tussock at normal maturity. A tussock is a tight clump of the lower parts of stems and leaves, dead stems and leaves, and the upper parts of roots or rhizomes.

**VEGETATION** (broadly) the plant cover of, the plant complex in, or the total plant assemblage in a landscape, region, state, etc. This is the common use of the term; (narrowly) any assemblage of plants regardless of uniformity or integration or lack thereof, individuality, or classificatory rank which for any reason is recognized as a unit. Plant communities and associations as well as completely heterogenous or random assemblages may be specified. A vegetation, a soil and a climate constitute a meaningful complex-unit in nature and a unit of central interest in geobotany. These three components along with a fauna and a decomposer biota constitute an ecosystem.

**VEGETATION MAP CORRECTNESS** the validity of a vegetation map as an abstraction, or a representation, of the vegetation in the landscape, in the context of map scale and the assumptions (pertaining mostly to vegetation class breadth, most prevalent vegetation, and minimum map unit size) upon which the map is based. The degree of correctness may be determined through verification (qq.v.) and expressed by a figure on a percentage scale.

**VEGETATION MAP PROBABILITY** an average of map unit class probabilities weighted according to relative areas occupied on the map. A map unit class probability is the probability that at any point in a class unit the indicated vegetation is acutally represented at the equivalent point in the landscape. Probabilities tend to be less than 100 percent because only the areally most prevalent vegetation is identified for a unit.



VEGETATION SCIENCE the area of specialization in geobotany concentrating on the description and explanation of plants in the assemblage, with principal concern for the concepts of plant community, continuity in vegetation, and vegetations as environmental indicators.

VERIFICATION the process of determining how well a vegetation map represents reality, involving checking a representative set of sample map units against information, mostly from the field and/or air photos, additional to that used in the original mapping.

WESTERN HEMLOCK Tsuga heterophylla (Raf.) Sarg.

WHITE SPRUCE Picea glauca (Moench) Voss.

WILLOW Salix L.

WOODLAND a vegetation featuring a very open upper layer of trees, small in most Alaskan cases, and a closed lower layer of shrubs, herbs or cryptogams. Woodlands are different from forests not only by present physiognomy, but also by dynamics in that the basic structure, with trees widely spaced in a closed lower layer, is a comparatively steady-state situation, a result of environmental and historical conditions different from those supporting or capable of supporting forests.

YELLOW CEDAR Chamaecyparis nootkatensis (Lamb.) Spach.